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Effects of Full-Tree Skidding and Livestock Grazing on Aspen Regeneration

by

Cameron Thomas Philip Lane ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment
of the requirements for the degree of Master of Science

in

Rangeland & Wildlife Resources

Department of Agricultural, Food and Nutritional Science

Edmonton, Alberta

Spring 1998

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UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Effects of Full-Tree Skidding and Livestock Grazing on Aspen Regeneration** submitted by **Cameron Thomas Philip Lane** in partial fulfillment of the requirements for the degree of **Master of Science** in **Rangeland & Wildlife Resources.**

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DATE: Jan 27, 1998

Dedication

This work is dedicated to my mother Barb, and my father Ron, for all their love and devotion.

ABSTRACT

This study investigated the effects of timber harvesting and livestock grazing on aspen regeneration and forage supply. Five skidding disturbances (no, light, moderate, heavy, and very heavy) as well as three decking disturbances (slash, burn, and road) were identified.

Increased skidding intensity reduced upland aspen stem density, vigor, biomass, and forage production at two years post-harvest. Skidding incorporated 91% of the cut-block area, of which, 7% severely reduced aspen regeneration. Decking disturbances, 9% of the cut-block area, also severely reduced aspen regeneration. In total 16% of the harvested area had problems regenerating aspen.

Two years of livestock grazing reduced aspen stem vigor on three skid distubances. Heavy, early season grazing reduced aspen stem vigor, biomass and forage production, whereas lighter, late season grazing did not affect aspen biomass. Grazing effects were most detrimental to aspen on light skidded disturbances. However, there are serious concerns with grazing effects on aspen production.

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To my family I am most thankful, for their loving support, encouragement, and for instilling that there is more to life than being a Pharmacist or Teacher. Thanks to my father, who claimed "[I'd] be a damn fool to pass up an opportunity to complete my Masters", to my mother who spent many hours watching me at the kitchen table and reminding me that someday "it will all be worth it", and to my brothers Kevin and Trent for their total disregard for my research and profession (ex. counting trees, watching grass-grow, cows eat trees) while reminding me to have fun and put things into perspective.

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I. INTRODUCTION

A PROBLEM ANALYSIS:

In the last decade, management of crown lands in western Canada have been a controversial subject as various industries compete for natural resources. In Alberta, crown land administered by Land & Forest Service was legislated to be managed under a multiple use mandate, in which land was recognized as a potential resource for all users. Because this mandate encouraged wide-scale resource allocations, crown lands have been awarded to forestry, livestock, and petroleum industries, creating multiple use landscapes. Such multiple use created conflicts between user groups when one infringed, or was perceived to infringe, upon the rights of another. Conflicting management objectives of the timber and range industries have created major confrontations on public forest leases (Clark 1975, Kosco and Bartolome 1981).

Alberta's north-central forested regions have been the focus of timber-range issues on aspen (*Populus tremuloides* Michx.) covered lands. In the past decades, crown grazing dispositions were issued within aspen dominated communities to provide an economical source of summer forage; at the time aspen was not considered a merchantible timber. The basis for timber-range resource conflicts developed as aspen became a merchantable timber species and timber licenses were issued.

In the early 1980's new technology and market demands established hardwood species such as trembling aspen and balsam poplar (*Populus balsamifera* L.) as key species for timber companies. Aspen timber products were used in the development of Orientated Strand Board (OSB), and pulp. In the Whitecourt area, deciduous harvesting commenced in 1982 for OSB, expanded again in 1986 for OSB, expanded in 1987 for pulp, and in 1989 increased yet again for use in news print (Darrah 1991). Land & Forest Service issued licenses to forest companies for aspen in response to the demand for more wood that overlapped existing grazing dispositions held for cattle producers. Land-use conflicts became apparent as the use of aspen stands for both the cattle and timber industries increased.

Conflicts between user groups arose from the narrowly focused objectives of each industry which ignored other user objectives. Forestry objectives were focused on tree harvesting and regeneration, while cattle producers required an economically viable and sustainable source of forage for summer grazing. Lack of appreciation for differing objectives and the inability to apply multiple use (forestry) and proper use (grazing) principles contributed to the resource based conflicts (Clark 1975, Nordstrom 1984). A broader approach was needed to incorporate both industries' management principles and objectives. Managing for sustainable resources required an integrated approach between user groups with an understanding of forest ecology, and the complex interaction of timber, forage, and cattle (Nordstrom 1984).

Timber-range management issues and conflicts have existed for decades. As early as the 1900's, cattle grazing had been implicated as a cause for poor ponderosa pine regeneration in the south-western United States. However, studies by Hill (1917) and Sparhawk (1918) demonstrated slight or negligible damage to pine seedlings by cattle grazing.

Forest industries were concerned about poor tree regeneration due to the destruction created by trampling and grazing of cattle (McLean and Clark 1980). Concerns related to poor tree regeneration lead to extensive studies by the Research and

Range Divisions of the BC Ministry of Forests, and the Agriculture & Agri - Food Canada Research Station at Kamloops. Research focused on the effect of grass seeding and grazing upon the establishment, survival, and growth of lodgepole pine (*Pinus contorta var. latifolia*) and engelmann spruce (*Picea engelmannii*) (Clark and McLean 1974, 1978). There is little documentation of forestry-range conflicts in Alberta. However, the issue remained apparent with both industries concerned that their rights and objectives were not being recognized by the other.

Regeneration Standards:

Forest companies are required to meet provincial reforestation standards as stipulated under "Free to Grow" regulations (Anonymous 1996). Standards vary according to sub-region, drainage class, and eco-site. Deciduous standards, within five years post-harvest, require 80% of plots surveyed to be stocked with approximately 7 500 stems/ha with an average stem height of 160 cm. If the forest companies do not adhere to these enforced standards, severe penalties can result. Forest companies are concerned cattle grazing may prevent adequate aspen regeneration; in contrast, the cattle industry is concerned with the long-term forage supply on their grazing dispositions.

Current forest harvesting, as practiced on a single management unit, uses a two pass harvesting system, where half the unit is logged on the first pass and the remaining timber logged within ten years following the initial cut. Although clear-cutting provided an increase in forage production following forest harvesting, dense deciduous regrowth reduced livestock access (Wheeler and Willoughby 1993). With a two-pass system, forage shortages may occur in 15 to 20 years, following harvest, depending on the density of aspen, associated vegetation, and the subsequent barrier to cattle grazing activities.

General Project Objectives:

There is a critical knowledge gap involving complex ecological interactions that needs to be filled before the appropriate landscape management decisions can be made. This project attempted to fill a portion of the knowledge gap by studying the impact of forest harvesting on aspen regeneration and its interaction with cattle utilization. Harvest skidding intensities, and decking disturbances, were characterized and examined for their effect on aspen regeneration. In addition, this project identified effects of cattle utilization on aspen regeneration, at three levels of skidding disturbance.

ASSOCIATED RESEARCH:

Reproduction of Aspen:

Aspen can reproduce in two ways: vegetatively (asexually) through root suckers, and sexually through seedlings. Sexual regeneration is less common than vegetative spread due to the demanding germination requirements and the inability of aspen to produce abundant, quality seeds on an annual basis (Maini 1968, Brinkman and Roe 1975). Aspen seeds are vulnerable to high mortality since they are short lived under natural conditions (Maini 1968). Since aspen seeds are intolerant of moisture stress, and high temperature at the soil surface, the timing of aspen seed dispersal must coincide with the demanding seedbed requirements. An adequate seedbed must have constant moisture (Fechner et al. 1981) and maintain a temperature of < 30 °C (McDonough 1979). Successful seedling establishment is rare; thus vegetative reproduction through root suckers is the normal form of regeneration of aspen stands.

Vegetative asexual reproduction is triggered by disrupting apical dominance (Peterson and Peterson 1992). However many critical controlling factors exist, as documented by Peterson and Peterson (1992): hormone regulation (cytokinin:auxin) (Farmer 1962, Steneker 1972, Schier 1976); soil temperature (Maini and Horton 1966, Gifford 1967, Perala 1974, Steneker 1974, Schier 1976); soil moisture levels (Maini and Horton 1964); root carbohydrate reserves (Schier and Zasada 1973, Schier 1976); inherent ability of the clone to sucker (Maini 1968); root size (Kemperman 1978); root depth (Horton and Maini 1964); and the degree of stand disturbance (Peterson and Peterson 1992).

Hormone Regulation:

Hormone interactions control apical dominance and regulate aspen sucker formation. Auxin is synthesized in the shoots and leaves, then translocated to the roots where it inhibits sucker growth and maintains apical dominance (Farmer 1962, Eliasson 1971b, 1971c, Schier 1973, 1981). Another hormone, cytokinin, is synthesized in the roots where it stimulates sucker initiation and growth (Peterson 1975). Therefore, the cytokinin:auxin ratio influences the emergence or suppression of aspen suckers. If the cytokinin:auxin ratio is low, suckering is suppressed (Winton 1968, Wilter 1968). A disturbance such as cutting or removal of the stem prevents the translocation of auxin to the roots thereby suppressing apical dominance and stimulating stem emergence (Schier 1974). Whenever auxin is either immobilized or destroyed, apical dominance is suppressed, and suckers develop.

Soil Temperature:

Maini and Horton (1964) observed that an increase in soil temperature after logging is the most critical stimulant for aspen suckering. Soil temperature must reach 20°C for maximum aspen sucker production (Steneker 1976). An increase in soil temperature lowers auxin levels and stimulates the production of cytonkinins, and suckering is initiated (Williams 1972).

Soil Moisture:

Adequate soil moisture is also critical for aspen suckering. Fralish (1972) indicated soil moisture was the most important factor in aspen growth. Aspen can persist on a wide range of sites, although it is mainly adapted to well-drained uplands with porous, loamy soils (Haeussler and Coates 1986). The effect of soil moisture cannot be isolated; rather, adequate soil texture and moisture conditions determine optimal sites (Sucoff 1982).

Carbohydrate Reserves:

Density of emerging suckers is related to parent stand condition and the level of carbohydrate reserves in the roots (Doucet 1989). Sucker regeneration, however is not normally limited by root carbohydrate reserves (Maini and Horton 1966, Williams 1972, Schier and Zasada 1973). Repeated destruction through browsing, burning, or spraying, can reduce carbohydrate reserves and reduce the density of emerging suckers (Baker 1918, Sampson 1919).

Inherent Ability of the Clone to Sucker:

Suckering potential is dependent on the state of the parent root system (Schier 1973, Perala 1978); this potential is reduced in decaying root systems of overmature stands. Initial aspen density, stand age, site, and clonal variability, are unique to each stand and influence suckering potential (Peterson and Peterson 1992). Genetic variations between clones may alter their inherent ability to sucker by as much as 20 times (Farmer 1962, Boekhoven 1964, Garrett and Zahner 1964).

Structure of the Clonal Root System:

Newly emerging aspen suckers are interconnected beneath the soil surface via a network of roots that emerge above ground as stems (Peterson and Peterson 1992). A single aspen clone is capable of spreading over 100 acres with 50,000 ramets (i.e. offspring produced from vegetative reproduction), all of which originate from a single ortet (i.e. the original plant from which a clone has been derived) (Kemperman and Barnes 1976).

A strong vertical root originating from the tree base is the center of the aspen root system. Several lateral roots originate from this base and produce numerous cord-like branch roots, which intertwine to create an underground matrix. This matrix, which becomes the initiation point for sucker emergence, is concentrated near the soil surface. Horton and Maini (1964) described the aspen parent root system as positioned horizontally through the soil medium and concentrated in the upper soil profile. Suckers arise from meristems initiated in bark near the cork cambium (Brown 1935, Sandberg 1951, Schier 1973), and the primordia produce buds that elongate into shoots (Schier 1974). These newly formed suckers rely on the parent root for nutrients (Peterson and

Peterson 1992) which, if readily available, provide emerging suckers with a distinct growth advantage over competing species (Graham et al. 1963). Such dependence on the parent root diminishes once suckers develop their own root system and become self-sufficient (Peterson and Peterson 1992).

Due to the location and vigor of roots in the upper soil horizons, aspen regeneration is vulnerable to surface soil damage caused by logging machinery. Root suckering is concentrated within 4 - 12 cm of the soil surface (Horton and Maini 1964, Strong and LaRoi 1983, and Navratil, 1991), and root diameters that range from 0.5 - 2.5 cm (Horton and Maini 1964). This concentration of the root system, at the soil surface, makes the maintenance of the soil surface critical for aspen emergence and survival (Strong and LaRoi 1983).

Stand Disturbance:

Forestry management objectives are to sustain aspen forest production following harvesting (Sheppard and Engelby 1983). Clear-cut harvesting is the most effective means of disrupting aspen apical dominance, thereby meeting management objectives (Schier 1981). Crouch (1983) and Bella (1986) explain that following clear-cutting, the emerging sucker stand often exceeds 50,000 - 100,000 stems per hectare. Successful regeneration therefore requires a healthy well-distributed root system and complete removal of stems to disrupt apical dominance (Schier 1974). Since partial cutting maintains apical dominance, aspen suckering is inhibited, and, as shown by Crouch (1983) and Bella (1986), previously established species such as alder (*Alnus spp.*) and other residual shrubs are able to out compete the shade intolerant aspen suckers.

The frequent promotion of aspen regeneration is necessary to prevent stand maturity. Apical dominance and a deteriorating root system inhibit new stem emergence in mature decadent stands (Schier 1974). Clear-cutting effectively promotes suckering by removing brush competition, thereby suppressing apical dominance and increasing soil and root temperature (Schier 1981 and Perala 1972). However, brush control must be limited as continual heavy traffic can damage shallow roots and prevent future suckering (Jones 1976).

Skidding traffic can reduce subsequent aspen suckering (Schier 1985). Intense skidding may reduce suckering directly by injury of the shallow, lateral parent root system, or indirectly through soil compaction and subsequent root mortality. Heavily disturbed sites adjacent to extraction roads had fewer aspen stems than lower trafficked areas (Zasada and Tappeiner 1969a, Shepperd 1993). Navratil (1991) explained that these heavily disturbed areas, created from the respreading of organic debris, promoted excessive competition from graminoid species, which subsequently reduced aspen growth. Although more heavily disturbed sites reduced aspen suckering, only a small percentage of the total harvest area was affected. Zasada and Tappeiner (1969) suggested that 75% of the harvest area was classed as undisturbed or slightly disturbed soil surface, while only 10% of the area displayed heavy soil disturbance.

Forest Harvesting Methodology:

Forest harvesting practices greatly affect the regeneration of forest stands (Jones and Shepperd 1985). Harvesting is a fundamental tool for sustaining timber production; however, methods are often influenced by economics, utilization standards, and equipment availability (Jones and Shepperd 1985). Zasada (1972) stated that skidding of entire trees (full-tree skidding), full merchantable lengths (tree-length skidding), or short form lengths (2.5 m), were all acceptable means of achieving successful aspen regeneration. Due to variations within site conditions, multiple-use objectives, and economics, harvesting prescriptions are made on a site-specific basis.

Impact of livestock grazing on forestry clear-cuts:

Cattle distribution on clear-cuts:

In order to maintain adequate forage production and range condition, management schemes are required to distribute cattle grazing pressures. Poor cattle distribution, which is influenced by cattle behaviour, creates uneven grazing pressure (Roath and Krueger 1982). Important parameters that modify animal behaviour include: distance to water, topography, forage, temperature, and humidity. Road construction will enhance cattle distribution by creating a gateway through broken terrain. Harvested cut-blocks have a network of logging roads and skid trails, creating major corridors throughout the area. Road construction and the presence of slash affect livestock access, altering grazing patterns and forage utilization (Edgerton 1971, Nordstrom 1984). Cattle enter cut-blocks from the main access roads and return to these roads during nongrazing periods (Roath and Krueger 1982). This continual cycling in and out of the cut-block creates an uneven grazing pressure, with heavier utilization near access roads and lighter utilization in more distant areas.

Willoughby (1994) studied cattle utilization patterns associated with aspen plant communities across the experimental area. Plant communities associated with upland sites received higher utilization than lower topographic areas. Increased grazing pressure altered understory plant composition, as shrubs and tall forbs were replaced with the following low forbs: strawberry (*Fragaria virginiana*), bunchberry (*Cornus canadensis*), wintergreen (*Pyrola asarifolia*), and clover (*Trifolium* spp.). Further grazing pressure reduced species' diversity, and subsequent invasion by Kentucky bluegrass (*Poa pratensis*), dandelion (*Taraxacum officinale*), and clover (*Trifolium* spp.) (Willoughby 1994).

Influence of livestock grazing on aspen regeneration:

Aspen is an important source of forage for domestic livestock and wildlife (Bailey 1981, FitzGerald and Bailey 1984). There is little published research addressing the cumulative effects of livestock grazing and forestry harvesting, on aspen regeneration and forage supply, in aspen forests of Alberta (Alexander and Bailey 1992). The Campbell Creek grazing trial, south of Grande Prairie, Alberta, was initiated in 1983 to monitor the effects of moderate livestock grazing pressure (1 AUM/acre) on aspen cut-blocks seeded with tame forages (Wheeler and Willoughby 1993, Sundquist 1995). Eight years after harvesting, grazed sites were stocked with 24 200 stems/ha, as compared to 36 000 stems/ha on ungrazed sites. At ten years post-harvest, aspen stocking patterns were maintained with 33 000 stems/ha with grazing and 38 000 stems/ha without grazing. Average stem height and volume were greater with grazing, indicating that grazing may be beneficial to sucker vigor by reducing vegetative competition. Research conducted near Rochester, Alberta, investigated the effect of domestic livestock on aspen communities, and revealed that cattle did not affect aspen growth with either light or heavy grazing intensities (Weatherill and Keith 1969).

Jones (1983) reported that cattle do have the potential to reduce aspen growth, depending on grazing pressure. Intensive grazing pressure removed grass and forbs, and defoliated the growing points of woody stems, thereby suppressing the regrowth of aspen and providing a competitive advantage to fast growing grasses and forbs. Lower stocking rates, however, enabled cattle to selectively graze grass and forb species, and ignore woody plants, thereby creating a competitive advantage for the undisturbed woody shrubs and trees (Jones 1983). Sampson (1919) found that grazing 50-60% of the available forage was adequate to maintain both mature, and young sucker aspen stands.

Influence of seasonal cattle grazing on aspen regeneration:

Timing of grazing throughout the growing season, however, affects cattle preference and the ability of vegetative species to persist under grazing. FitzGerald and Bailey (1984) studied the effects of cattle grazing on aspen survival during both early and late grazing seasons. Their research indicated that cattle preferred grass early in the growing season and avoided browsing aspen leaves until after herbaceous material was removed; therefore, aspen stems were able to resucker vigorously and remain dominant (FitzGerald and Bailey 1984). Late season grazing altered cattle preference, as aspen leaves were selected over mature grasses, thereby reducing sucker regrowth the following growing season (FitzGerald and Bailey 1984).

Influence of wildlife browsing on aspen regeneration:

At an early sapling stage, browsing by various wildlife species has been shown to alter aspen growth and survival (DeByle 1985). Mueggler and Bartos (1977) found that extensive browsing by deer prevented aspen regeneration on small clear-cuts, while aspen stands in elk winter ranges were also reduced by extensive browsing by elk (Graham et al. 1963, Krebill 1972, and Packard 1942). Moose also browse aspen stems extensively and have been known to knock down healthy aspen trees (Telfer and Cairns 1978). Browsing pressure is lowest in the summer, when the impacts are most severe, due to the abundance of available herbaceous material; it is highest in winter, when trees are dormant and herbaceous forage is relatively unavailable (Collins and Urness 1983). However, browsing during the dormant season seems to have only a pruning effect and does not influence survival the following spring, although simultaneous browsing by deer, elk and moose can permanently reduce aspen growth (DeByle et al. 1985).

Influence of wildlife browsing and cattle grazing on aspen regeneration:

Wildlife browsing is seasonal based on animal species, while grazing is seasonal based on available forage (DeByle et al. 1985). It is generally accepted that if grazing is light to moderate, browsing will also be light-moderate. Elk and cattle both select grasses, however elk impacts are negligible on cattle summer range. However, intensive cattle grazing on elk winter range can force elk to browse aspen suckers, which may significantly affect aspen stand survival (DeByle et al. 1985). Julander (1955) identified a similar relationship between deer and cattle grazing effects on aspen stands. Grazing, browsing, and trampling by cattle, sheep, and ungulates can impede the growth and survival of aspen, necessitating regulation of animal populations and control of grazing distributions (Greenway 1990). Greenway showed that wildlife populations, managed at carrying capacity, repeatedly browsed aspen suckers, increasing the density of conifer, shrub, and grass species. In order to reduce grazing impacts, livestock were reduced and/or removed 5 - 10 years post-harvest, and wildlife control measures were implemented to ensure successful aspen regeneration (Greenway 1990).

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II. ASSESSMENT OF SOIL AND GROUND SURFACE DISTURBANCES FOLLOWING FULL-TREE HARVESTING OPERATIONS.

INTRODUCTION:

In Alberta, increased demands for aspen (*Populus tremuloides* Michx.) fibre products have encouraged new forest companies to harvest the aspen forests (Darrah 1991). Natural aspen regeneration was assumed to simplify post-harvest management of these forests (Navratil, 1991) because aspen clones readily form root suckers. Nevertheless, unsatisfactory aspen regeneration is evident in some clear-cuts; this challenges forest managers to reexamine harvesting methodology and post-harvesting management. Harvesting techniques involving skidding patterns, intensities, equipment, and scheduling are known to be important factors affecting successful aspen regeneration (DeByle 1976, Bella 1986). However, regeneration is often restricted by an undesirable combination of site, and harvesting techniques (Navratil 1991). Harvesting operation schedules are required on a site-specific basis, as prescriptions must be altered to account for variations in vegetative, soil, slope, and moisture conditions.

Regeneration following harvesting is further dependent upon the status of the parent root system. A shallow, and relatively slender parent rooting system is the main source for vegetative propagation (Horton and Maini 1964, Strong and LaRoi 1983, and Navratil 1991). Damage to these roots, through ground surface scarification during forest harvesting is real. This makes the selection of forest harvesting methodology critical for successful vegetative regeneration of aspen (Navratil 1991).

Clear-cut harvesting by full-tree skidding is widely recognized as an acceptable harvesting technique for successful aspen regeneration (Zasada and Tappeiner 1969b, Zasada 1972, Jones and Shepperd 1985, Navratil 1991). Because skidding also damages understory shrubs, it is an effective means of reducing vegetative competition and thus regenerating pure aspen stands (Zasada and Tappeiner 1969a). Soil disturbance and slash accumulations are also minimized using full-tree skidding (Jones and Shepperd 1985).

Although clear-cut harvesting is capable of producing optimal conditions for aspen regeneration, it can also reduce regeneration depending upon the type and timing of harvesting and soil conditions (Navratil 1991). Harvesting operations can cause soil physical disturbance or accelerated organic matter decomposition and nutrient leaching (Alban 1991); removal of organic matter and increased soil compaction are often evident on with low aspen regeneration following harvesting. There is a need to quantify key soil factors, and assess harvesting impacts, on aspen regeneration (Alban 1991).

Soil compaction incurred during forest harvesting can alter soil strength, aeration, infiltration rate, moisture, and nutrient regimes, which affect tree preformance (Alban 1991, McNabb 1992a). Froehlich and McNabb (1984) showed an asymptotic curvilinear relationship between increased bulk density and increased vehicle trips, where most soil compaction occurred with the first few passes. Decreases in conifer height growth sometimes may be related to increases in bulk density. Few studies, however, have successfully measured the effects of soil compaction on aspen regeneration. Alban and Perala (1990) found that winter harvesting over snow-covered, frozen ground did not affect soil bulk density or aspen regeneration.

However, Alban (1991) argued that the ability to relate harvesting compaction to aspen growth on a site-specific basis was futile since soil bulk density was viewed as a poor indicator of plant performance. Soil compaction measured by bulk density is independent of soil shear strength; as a result, low or undisturbed bulk density can have significantly higher shear strength than soils with high bulk density (McNabb 1992a). Since soils with higher shear strength are less compressible than soils with a lower strength, shear strength is not related to the bulk density of different soils. Because of this, soil shear strength is reported as a better indicator of soil degradation (Froehlich and McNabb 1984, and McNabb 1992a).

In a review of the literature between 1970 to 1977, Greacen and Sands (1980) showed that 12 percent of harvesting studies did not find soil compaction reduced tree production. The relationship between plant growth and bulk density is not direct but rather an association that cannot be extrapolated to unlike soils or sites (Froehlich and McNabb 1984, McNabb 1992a,b). Plant response to soil disturbance is not only affected by the type and severity of disturbance, but by the unique site and climatic conditions where it occurs (McNabb 1992a). A change in stress in a plant's operational environment must modify its physiological processes before a change in plant performance is observed.

McNabb (1992a) defined a plant's operational environment as the portion of the environment that involves a direct transfer of energy and mass between the plant and its environment. Plant performance is not affected if the factors involved in soil-plant energy transfers of heat, radiation, water, gases, and nutrients are not altered by increased soil compaction (McNabb 1992a). Therefore, an increase in soil bulk density may not affect plant growth (McNabb and Campbell 1985). An inability to isolate energy and mass flow processes between soil and plant has restricted the success of current studies to relate forest harvesting soil compaction to tree regeneration or survival (Alban 1991, McNabb 1992a,b).

This study was conducted to test the hypothesis that no relationship existed between selected soil disturbance measurements and skidding disturbances. This study also tested the hypothesis that roadside logging operations had no effect on ground cover.

Relating the effects of harvesting soil disturbance to aspen growth was not the objective of this project. Rather, quantitative soil disturbance measurements were utilized to verify visual on-site estimates of harvesting disturbances. Empirical analysis of soil disturbance and measures of site disturbance were utilized in subsequent chapters to assess the effects of disturbance on aspen regeneration. However, cause and effect relationships between soil and plant interactions are complex (Alban 1991) and beyond the focus of this project.

EXPERIMENTAL AREA:

Location

The experimental area was located 15 miles north of Nojack, Alberta, west of Highway 751 (Section 19-21, 28-30, Township 056, Range 11, West of the fifth meridian).

Climate

Wide distribution of aspen across North America indicates that it is adaptable to a range of climatic and microsite conditions. Cold continental and boreal climates are ideal conditions for aspen growth, as aspen has a high resistance to frost and freezing conditions without snow cover (Haeussler and Coates 1986). Aspen is generally adapted to well-drained uplands. In addition to its low water demands, aspen stands and emerging suckers are shade intolerant, requiring full sunlight for optimal stand growth and survival.

Geology and Soils

Parent material, deposited by continental ice sheets, was early tertiary till of Paskapoo Formation origin (Alberta Energy and Natural Resources 1978). This geological formation was characterized by horizontally bedded, medium to weakly cemented sandstone, soft shale beds, coal, and tuff. The landscape was characterized by sinuous, narrow till plains elevated between 2800 to 3200 feet Above Sea Level (ASL) and was overlain by a shallow, discontinuous outwash and slopewash deposit material. The landscape topography was moderately well drained with undulating (2-5% slope) to moderate rolling (9-15%) slope. Soils consisted of orthic gray luvisol, clay loams from the Hubalta soil series. McNabb (1994) showed an average bulk density of 1.18 Mg m^{-3}, within the 0-10 cm soil depth, within these soil types. These heavy clay soils have low organic matter and available plant nutrients, such as nitrogen and potassium, creating poor to fairly good arable soil (Twardy and Lindsay 1971).

Vegetation

The experimental area was situated in the Lower Boreal Cordilleran Ecoregion and the Southern Alberta Uplands Ecodistrict (Strong and Leggat 1992). Prior to harvesting, the area was dominated by *Populus tremuloides-Populus balsamifera/Alnus crispa/Calmagrostis canadensis* situated along midslope positions. Lower, moister landscape positions contained *Populus tremuloides- Populus balsamifera/Alnus tenuifolia-Alnus crispa/Calamagrostis canadensis*, while drier uplands produced *Populus tremuloides-Populus balsamifera/Fragaria virginiana/Calamagrostis canadensis* (Willoughby 1994). Average biomass production was 1459 kg/ha, although a high cover of alder in the understory limited livestock use (Sundquist et al. 1997).

Forest Harvesting

The forest harvesting system included clear-cutting with full-tree skidding in alternating cut-and-leave blocks on a two-pass harvest plan. Weyerhaeuser Canada Ltd. supervised the logging operation according to the Alberta Timber Harvesting Planning and Operation Ground Rules (1994) and the Weyerhaeuser Annual Operating Plan. Logging services where provided by Art Peyton Logging Ltd.

Harvesting equipment

Falling	2 - 618 Timberjack Feller Bunchers (20” Harricana Head)
Skidding	3 - John Deere 748 Grapple Skidders, with low ground pressure, high floatation tires.
Delimbing	1 - 300 cat - 2200 Lim-mit Delimber 2 - 892 JD 2200 Lim-mit Delimber
Slashing	2 - Hood Self - Propelled
Loading	2 - Cat 300 Knuckle Boom Loaders
Road Const.	1 - Cat D7H c/w Ripper 1 - Cat D7G 1 - Champion 740 Grader 1 - 690 JD Excuvator

(Weyerhaeuser 1996).

Full-tree skidding

The full-tree harvesting system restricted work at the stump to falling the tree by a feller-buncher. Trees were forwarded by a four-wheel drive, rubber-tire grapple skidder from the stump to the decking site for limbing and cutting into shorter logs (2.6 m) (Zasada and Tappeiner 1969a, Weyerhaeuser 1996). Skidding created a series of long narrow forest trails (skid-trails) from stump to decking sites; repeated use of skid-trails removed standing vegetation and increased soil exposure.

Soil disturbance

Grapple skidders were equipped with low ground pressure, high floatation tires as a precaution against extensive soil compaction (Weyerhaeuser 1996). Because the schedule for summer harvesting was influenced by site-specific weather and soil moisture conditions, areas sensitive to soil degradation or site disturbances, were identified and restricted from harvest. As a result, logging operations were terminated after extended periods of moisture, as moist soils were sensitive to compaction created by intensive traffic (Weyerhaeuser 1996).

Slash disposal

Following skidding, further processing consisted of limbing, cutting, and stacking of the aspen logs along the road-side or decking site. Heavy slash accumulations, created from the limbing process, were piled and burned, while lighter slash accumulations were spread throughout the decking area (Weyerhaeuser 1996).

Logging road

Road construction occurred in two-phases. Preharvest road construction involved excavating upper organic layers and vegetation (graders level and compact the mineral layers) which formed a hardpan road adequate for large flat-bed trucks to travel upon. After harvest, roads were deep ripped and scattered with forest floor top soil and accumulated woody debris from the limbing process.

METHODOLOGY:

Experimental Design

Six cut-blocks were harvested during the summer of 1994, utilizing full-tree skidding in accordance with Alberta Timber Harvest Planning and Operating Ground Rules (1994) and Weyerhaeuser's 1994 Annual Operating Plan. A randomized complete block design was used with six blocks and eight treatments (five skidding and three decking disturbance treatments). Sampling was conducted in six, 2 m^2 permanent plots randomly distributed within each combination of block and treatment.

Harvesting disturbances were estimated based on knowledge of full-tree skidding and the location within the cut-block. For example, soil adjacent to decking areas received more intense traffic (heavy skidding traffic) than those near the cut-block boundary (light skidding traffic). No-skid areas consisted of narrow unlogged strips with an undamaged understory and various unmerchantable trees, including birch (*Betula papyrifera* Marsh.), alder (*Alnus crispa* (Ait.) Pursh), and willow (*Salix spp.*). Five levels of skidding damage (no, light, moderate, heavy, and very heavy), and three decking disturbances (slash, burn, and road) were identified.

The following descriptions define skidding and decking disturbances based on a visual assessment of these disturbances following harvesting operations.

1. No-skid – Ground cover was undisturbed with a high percentage of both vegetative litter and accumulated debris consisting of a dense grass and shrub layer.
2. Light skid – Similar to no-skid, but had at least one skidder pass, with a high percentage of both litter and debris cover, and little soil exposure.
3. Moderate skid – It was intermediate between low and heavy skidding, and displayed a decline in litter and debris cover and an increase in soil exposure relative to light skidding.
4. Heavy skid – This treatment had little litter, debris, or slash accumulation but it displayed high soil exposure.
5. Very Heavy skid – Similar to heavy skid, this treatment displayed lower litter and debris cover, and conversely higher soil exposure.

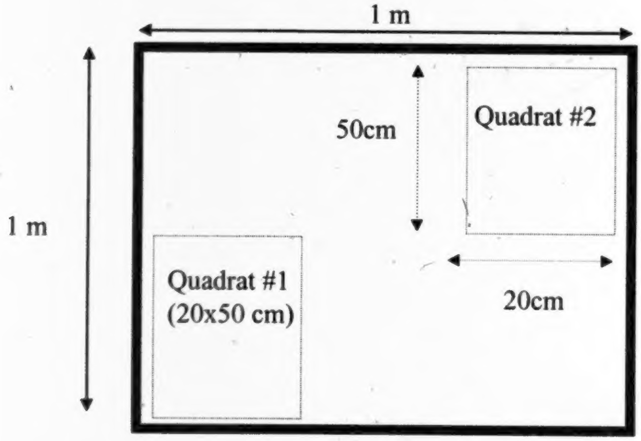
Three unique decking disturbances were identified and were defined as the following:

1. Slash – Characterized by high woody debris cover (CWD and FWD) and slash accumulation (cm), with little exposed soil.
2. Burn – Predominately covered by ash, with relatively low woody debris.
3. Road – High mineral soil exposure with fragments of woody debris.

Measurements

Soil disturbance measurements were used to quantitatively define each estimated harvest disturbance treatment. Percent ground cover was recorded within each harvesting treatment, in a 2 m^2 permanent plot. Ground cover was estimated within two 20 X 50 cm quadrats within a single 1 m^2 quadrat (Figure 2.1). The following cover estimates were made at each plot: percentage of course woody debris, fine woody debris, vegetative litter accumulation, exposed soil organic matter, exposed mineral soil, and ash. In addition to these estimates, the depth of slash accumulation was also measured in centimeters.

Figure 2.1 Position of 20 x 50 cm quadrats within 1 m^2 of the permanent plot for cover estimates.



Coarse Woody Debris (CWD) was defined as any woody material ≥ 2 cm in diameter, Fine Woody Debris (FWD) was < 2 cm in diameter, and Total Woody Debris (TWD) = CWD + FWD. Litter was defined as any dead vegetative material covering the ground surface (Debris (D) = CWD + FWD + litter). Exposed soil organic matter referred to dark organic matter on the ground surface, while mineral soil referred to any silt, sand, or clay that was exposed (Total Exposed Soil (TES) = organic + mineral). Ash, found only on the burned sites, referred to the blanket of burned debris. Slash accumulation, measured in centimeters, was averaged from three sample points within each 20 x 50 cm quadrat. Cover estimates were based on 10% intervals; if cover < 10% then 1% intervals were used. The Total Cover (TC) equaled 100%.

Soil bulk density was measured on four levels of skid-trail disturbances (no-skid, light, moderate, and heavy skid). Within each skid treatment, in each cut-block, three soil core samples were extracted from a five to eight centimeter depth within the mineral soil adjacent to each permanent plot. Samples were extracted by a soil probe and a metal cylinder (3 cm in height and 7.6 cm in diameter), sealed in a plastic bag, and wrapped in a paper bag. Before air drying the core samples were removed from the plastic bags and wrapped in the paper bags. Samples were dried, weighed, and recorded in grams.

Spatial distributions of each harvesting treatment were assessed using 65 x 65 m grid (north-south, east-west) transects across cut-blocks. Grid transect points were classified, based on location within the cut-block and knowledge of the harvesting system, into harvesting disturbance treatments (no-skid, light skid, moderate skid, heavy skid, very heavy skid, slash, burn, and road), and drainage classes (well-drained/upland, and poor drained/depressional). The percent of treatment and drainage class coverage from the three hundred microsite plots was calculated.

Data Analysis

The model for analyzing the effect of harvesting treatments on ground cover and soil bulk density was:

$$Y_{ijk} = B_i + T_j + e_{ij} + E_{k(ij)}$$

Where: Y = Dependent variable.

B = Block.
T = Forest harvesting treatments.
e = Experimental error.
E = Sampling error.

Computations for analysis were made for the above model using the GLM procedure of SAS (SAS Institute, Inc. 1989). Skid disturbances were assigned to categories of disturbance (no-skid = 0, light skid = 1, moderate skid = 3, heavy skid = 5, very heavy skid = 7) to determine whether a relationship existed between skid disturbances and dependent variables. Quantitative skid-trail values were based on relative intensities of machinery traffic. Narrow skid-trails close to decking areas received high machinery traffic (very heavy to heavy skid), whereas skid-trails close to cut-block boundaries, away from decking, received less machinery traffic (moderate skid to light skid). These criteria were used to identify skid-trail disturbances and can be replicated visually on cut-blocks where full-tree skidding has been utilized. The Dunnett's Test was used to compare decking disturbances with no-skid, and thereby classify decking disturbances based on ground surface conditions.

RESULTS:

A grid system, of the entire harvested area, identified the distribution and magnitude of ground surface disturbances created by full-tree skidding (Table 2.1). Skid disturbances occupied most of the cut-block area (91%). Light skidding categories (no, light, and moderate) occupied 72% of the cut-block, heavy skidding categories (heavy and very heavy) occupied 19%, and decking disturbance categories (slash, burn, and road) covered a lower proportion of the cut-block land base (9%). The landscape predominately consisted of a moderately rolling topography with approximately equal percentages of well-drained uplands (51%) and poorly-drained micro-site depressions (49%).

Skidding

Positive linear relationships existed between estimated skid-trail disturbances and exposed organic matter, total exposed soil, and Fine Woody Debris (FWD) (Figure 2.3). Negative linear relationships were found between skidding intensity and debris, and litter cover (Figure 2.4). A negative linear trend was also developed between skidding intensity and depth of slash (Figure 2.5).

The effects of soil bulk density on four levels of skidding also showed a positive linear trend ($R^2 = 0.85$) (Figure 2.6). However, the variation among skid treatments, across the six cut-blocks was substantial. Variation amongst the cut-blocks was apparent as the average bulk density mean, for cut-block 1 was significantly greater than means from cut-blocks 2, 4, 5, and 6 (Table 2.2). As well, the average bulk density from cut-block 3 was significantly greater than average bulk density means from cut-blocks 4 and 5. Differences amongst skidding treatments were also apparent, as heavy skidding was significantly greater than no-skid and light skid. As well, moderate skidding had a significantly greater soil bulk density than no-skidding. Analysis of variance for dependent variables on skidding disturbances are presented in Appendices 6.1.

Decking

Three unique decking disturbances were identified by comparison with no-skid disturbance (Table 2.2, Appendices 6.2). There was a significant amount of woody debris, exposed mineral soil, and ash for slash, road, and burn disturbances respectively.

DISCUSSION:

Decking

There were three discrete decking treatments that produced severe ground surface disturbances. Although decking sites occupied only a small portion of the cut-block area, the amount of surface disturbance and potential damage to the underlying root system may severely limit aspen regeneration. Temporary haul road disturbances severely degrade soils by compaction and remoulding (McNabb 1994). However, the tillage of haul roads, and pull back of soil and woody debris is a rehabilitation process to establish conifer seedlings since the aspen parent root system was removed with the soil surface horizons. In the burn and road disturbances, there is a substantial loss of organic matter and aspen roots (Navratil 1991). The woody debris on slash disturbances would likely create colder, less favorable microsites.

Skidding

Increased skidding intensities were associated with increased ground surface disturbance, such as removal of standing vegetation and exposure of organic and/or mineral soil layers. These relationships between estimated forest harvesting disturbances and ground cover measurements established a linear skidding intensity gradient within the cut-block area.

A study by Zasada and Tappeiner (1969b) measuring soil disturbances created by rubber-tire skidders on full tree-length, summer harvested aspen cut-blocks, further supported these treatment classifications. They identified five soil disturbance levels (light, medium, heavy, none, and none/slash) based on inspection during and following harvesting on four logged sites. Light, medium, and heavy disturbances were relative levels based on qualitative assessments of traffic intensity. Removal of the litter and shrub layer, exposed mineral soil, depth of root damage, and surface soil compaction increased from light to heavy disturbances. Approximately 39-44% of the area was undisturbed, 23-37% was lightly disturbed, 10-22% displayed medium disturbance, and 7-11% was heavily disturbed. These disturbance percentages were similar to those found within the experimental area, especially on moderate to heavy levels of skidding (Table 2.1).

Increased skidding intensity resulted in a significant increase in soil bulk density under moderate and heavy skidding (Table 2.2). Linear trend analysis on soil bulk density also supported the effects of skidding intensity. However, Froehlich and McNabb (1984) showed an asymptotic curvilinear relationship between increased bulk density, averaged over 0-20 cm layer, and increased vehicle trips, where most soil compaction occurred with the first few passes. Due to the lack of information, within the experimental area, on pre-harvest soil conditions, and the inability to isolate the number of skidded passes with levels of skidding, linear trends of soil bulk density with skidding intensity cannot be accepted based on what is currently known. Nevertheless, the analysis of variance did establish a significant increase in bulk density with higher skidding intensity, despite the tremendous variation in bulk density within sampled cut-blocks (Figure 2.6). These differences are likely due to differences in soil texture and drainage. This amount of variation, subsequently, effected analysis and interpretation of sampled vegetation within the experimental area.

There were large differences in areas occupied by the various disturbance classes. Full-tree skidding greatly disturbed a relatively small portion of the cut-block (heavy and very heavy skidding 19% of the harvested area). Repeated use of skid-trails, however, focused intense harvesting traffic along narrow, corridors and decking sites, adjacent to the extraction roads, thereby maintaining a relatively undisturbed and viable aspen root system throughout most of the cut-block. The portions of the cut-blocks that were not disturbed by skidding (30%) was partly due to random skidding operations and partly due to the successional stage of the parent aspen stand. Aspen stands mature between 60 and 80 years, and deteriorate rapidly after 120 years. As the old canopy gradually breaks up the deteriorating clones are often replaced by herbaceous and shrubby understories (Mueggler 1989). Therefore, the distribution of the parent stand affected how the trees were felled and where they were skidded.

Soil disturbances identified and characterized relative levels of forest harvesting disturbances, however, this project will not relate cause and effect relationships between soil disturbances and aspen regeneration. The relationship between soil disturbance and plant performance involves a complex series of mass and energy transfers unique to site and climatic conditions (McNabb and Campbell 1985, McNabb 1992a). Inability to isolate the effects of dependent variables restricts the ability to relate soil disturbance to plant performance (Alban 1991, McNabb 1992a,b).

CONCLUSIONS:

A positive linear relationship existed between skidding disturbances and soil ground cover measurements. As well, soil compaction significantly increased with moderate and heavy skidding. This relationship established a linear skidding intensity gradient that consisted of the following skidding disturbances: no-skid, light, moderate, heavy, and very heavy, and confirmed the use of visual disturbance classification system for the remainder of this study. This classification system was established despite, a significant amount of site variation within the experimental area.

Table 2.1 Spatial distribution (% cut-block area) of identified forest harvesting classifications.

Forest harvesting disturbance		N = sample size		% cut-block area (N = 300)	
No-skid (N)		83		28	
Light skid (L)		90		30	
Moderate skid (M)		42		14	
	Subtotal lightly skid (N+L+M)		215		72
Heavy skid (H)		37		12	
Very Heavy skid (VH)		22		7	
	Subtotal heavy skid (H+VH)		59		19
	Total skid (N+L+M+H+VH)		274		91
Burn (B)		3		1	
Road (R)		15		5	
	Extreme disturbance (B+R)		18		6
Slash (S)		8		3	
	Total deck (S+B+R)		26		9
Well-drained upland		153		51	
Poorly-drained depression		148		49	

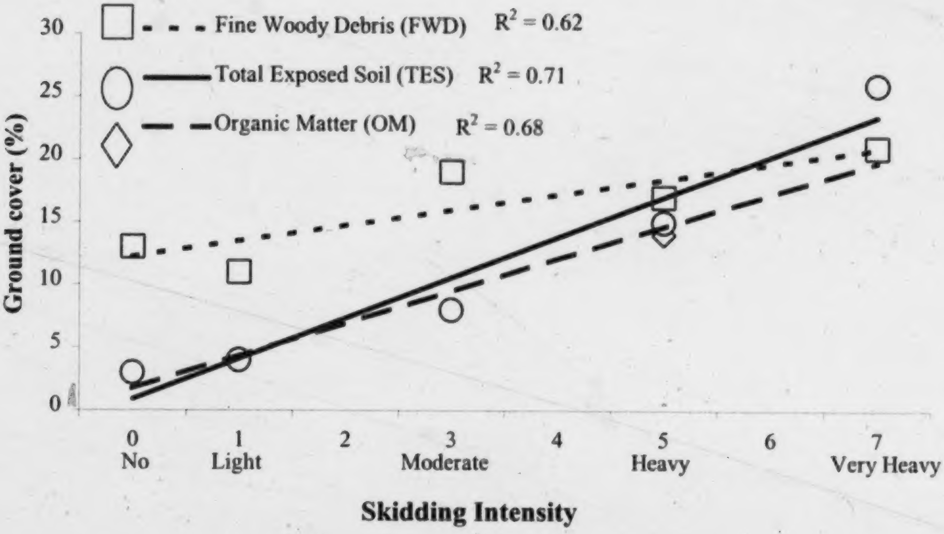


Figure 2.3 The relationship between ground cover estimates of Fine Woody Debris (FWD), Total Exposed Soil (TES), and Organic Matter (OM) and skidding intensity. Data points were the average of 36 observations; the average standard deviations of samples within block and treatment combinations were 4.2, 7.7, and 5.7 for FWD, TES, and OM respectively. All linear trends were significant at $p<0.05$.

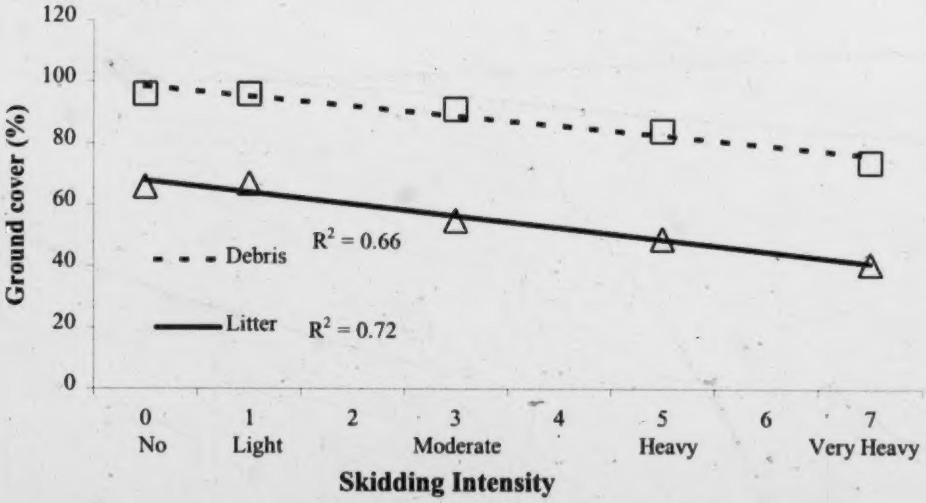


Figure 2.4 The relationship between debris-litter cover estimates and skidding intensity. Data points were the average of 36 observations; the average standard deviations of samples within block and treatment combinations were 7.7 and 7.3 for debris and litter respectively. Both linear trends were significant at $p<0.05$.

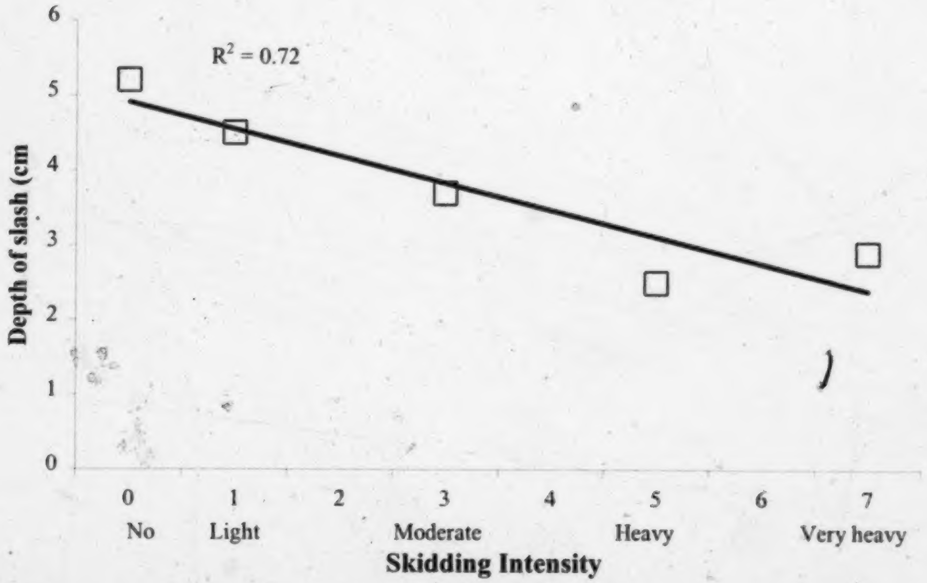


Figure 2.5 The relationship between slash accumulation and skidding intensity. Data points were the average of 36 observations; the average standard deviation of samples within block and treatment combinations was 1.3. The linear trend was significant at $p<0.05$.

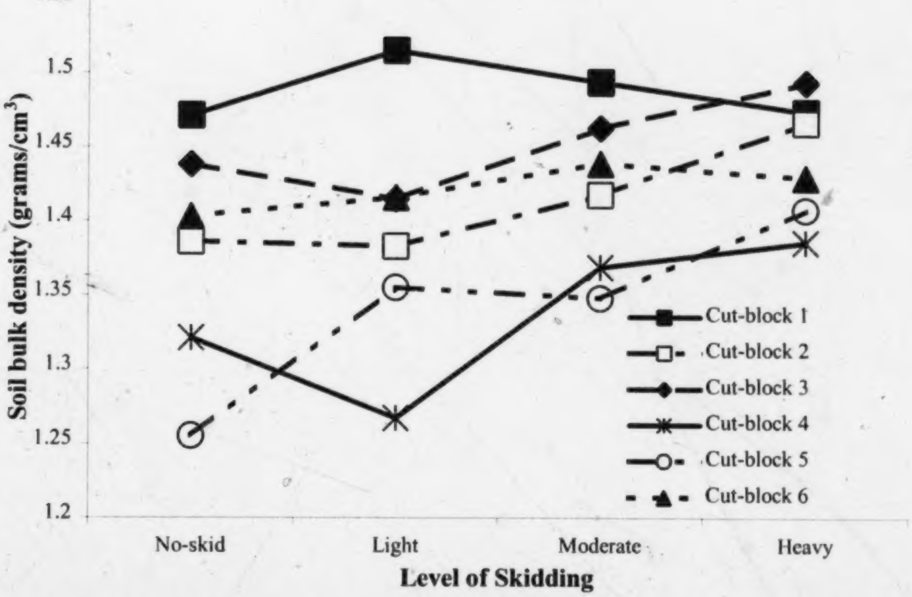


Figure 2.6 The relationship between soil bulk density and four levels of skidding. Data points were the average of 18 core samples; variation of average skid treatment data points, across the six cut-blocks, was 15%, 16%, 10%, and 7% for no-skid, light, moderate, and heavy skid respectively.

Table 2.2 Comparisons of average soil bulk density across six cut-blocks, and four levels of skidding.

	Mean (grams/cm³)		**Mean (grams/cm³)**
Cut-block 1	1.49a	No-skid	1.38c
Cut-block 2	1.41b	Light	1.39bc
Cut-block 3	1.45ab	Moderate	1.42ab
Cut-block 4	1.34c	Heavy	1.44a
Cut-block 5	1.34c		
Cut-block 6	1.42b		

Columns with the same letter are not significantly different according to Fisher's Least Significant Difference procedure ($p<0.05$).

Table 2.3 Comparisons of ground cover parameters between decking and no-skid treatments following forest harvesting.

	Course woody debris	Fine woody debris	Total woody Debris	Litter	Debris	Organic matter	Mineral Soil	Total soil	Ash	Slash depth
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(cm)
No-skid	17 (5.9)	13 (4.5)	30 (6.8)	66 (6.9)	96 (6.5)	3 (4.9)	0	3 (5.9)	0	5 (1.5)
Slash	31* (5.9)	24* (4.5)	56* (6.8)	42* (6.8)	98 (6.5)	3 (4.9)	0	3 (5.8)	0	9* (1.5)
Burn	8 (6.6)	8 (5.0)	16 (6.7)	1* (6.7)	17* (7.4)	3 (5.5)	1 (9.8)	4 (6.6)	79* (2.1)	0
Road	13 (5.9)	13 (4.5)	26 (6.7)	7* (6.9)	33* (8.4)	10 (4.9)	56* (9.6)	66* (5.9)	0	1 (1.5)

Means within a column with * are significantly different from no-skid according to The Dunnett's Test ($p<0.05$), 95% confidence limits (+/-) indicate variation of the means.

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III. EFFECT OF SUMMER HARVESTING BY FULL-TREE SKIDDING ON UPLAND ASPEN REGENERATION AND FORAGE SUPPLY.

INTRODUCTION:

Trembling aspen (*Populus tremuloides* Michx.) is the most widely distributed native tree species in North America (Jones 1985). In the Prairie Provinces, hardwood species such as trembling aspen and balsam poplar (*Populus balsamifera* L.) make up one-quarter of the 4327 million dry tonnes of standing timber (Bonnor 1985). Alberta alone has over 6.8 million hectares of pure aspen stands which are affected by the multiple activities of forestry, oil, gas, domestic livestock, wildlife, watershed, and recreational use (Wheeler and Willoughby 1993). In north-central Alberta, harvesting of deciduous timber has expanded on three occasions since the 1980's to meet increasing consumer demands for oriented strand board, pulp, and chopsticks (Darrah 1991).

North-central Alberta has been the focus of extensive aspen timber extraction by Weyerhaeuser Canada Inc., which has the rights to harvest timber in the area by means of Deciduous Timber Licences and Forest Management Agreements. These timber rights also give Weyerhaeuser the responsibility for regenerating harvested areas.

Following harvesting, aspen regeneration is facilitated by the clonal nature and prolific suckering of aspen stands (DeByle 1976, Navratil 1991). Controlling skidding patterns, intensities, equipment, and scheduling are critical to this regeneration (DeByle 1976, Bella 1986). Despite the vegetative regeneration of aspen, an undesirable combination of site, silviculture and harvesting practices can eliminate or limit this natural process (Navratil 1991). Therefore, site specific harvesting decisions are required to account for variations in vegetation, soil, slope, and moisture.

Clear-cut harvesting by full-tree skidding is widely recognized as an acceptable harvesting technique for promoting successful aspen regeneration (Zasada and Tappeiner 1969ab, Zasada 1972, Jones and Shepperd 1985, Navratil 1991). Full-tree skidding restricts work at the stump to falling the tree with a feller buncher. Jones and Shepperd (1985) explain that this forest harvesting system minimizes soil disturbance and slash accumulations.

Summer harvesting by full-tree skidding is an effective means of removing excessive shrub and herbaceous competition, while scarifying thick duff layers to maintain a dominant aspen stand (Zasada and Tappeiner 1969a, Bella 1986, Navratil 1991). Complete removal of the aspen stand suppresses apical dominance while increasing soil-rooting temperature and light penetration, thereby initiating prolific suckering (Maini and Horton 1966, Steneker 1974, Bella 1986, Navratil 1991). Low root carbohydrate levels in the middle of the growing season, however, may decrease the number and vigor of suckers following summer harvesting (Navratil 1991). Due to excessive soil disturbance and/or compaction created by skidding traffic with summer harvesting (Maini and Horton 1964, Perala 1978, Zasada and Tappeiner 1969a), aspen regeneration may be reduced as a result of injury to the root medium (Weingartner 1980, Zasada and Tappeiner 1969a, Navratil 1991).

Aspen stems are interconnected beneath the soil surface by roots that emerge above ground as stems (Peterson and Peterson 1992). Root systems are concentrated near the soil surface to utilize nutrients concentrated within the upper organic soil layers (Sollins et al. 1980).

The aspen root system is concentrated within 4 to12 cm of the soil surface, (Horton and Maini 1964, Strong and La Roi 1983, and Navratil 1991) with root diameters ranging from 1.3 to 5.0 cm in diameter (Maini 1967, Kemperman 1978). However, most aspen suckers arise from lateral roots less than 2 cm in diameter (Peterson and Peterson 1992). The position and vigor of the rooting system makes the maintenance of the upper soil horizons critical for aspen survival and shoot emergence (Strong and LaRoi 1983). Navratil (1991) explained that rooting damage depends on site-specific conditions, with increasing damage related to wet soil conditions. Aspen requires a proper balance between soil moisture and aeration to regenerate and survive; identifying site conditions is essential for proper harvest scheduling.

Numerous related studies on aspen regeneration following harvesting suggest prolific aspen suckering with 50 000 to 100 000 stems/ha (Crouch 1983, Doucet 1989, Bella 1986). A study in Hudson Bay, Saskatchewan, produced 200 000 stems/ha the first year post-harvest (Bella 1986). Perala (1978) suggests 125 well-distributed parent trees or 5 m^2/ha basal area is required to regenerate a fully stocked stand. Recommended minimum density and stocking levels vary and are difficult to prescribe due to the high mortality induced by competition at a site-specific level (Bella and DeFranceshi 1972). However, Perala (1978) advised that at least 10 000 stems/ha at two years was required to compensate for natural thinning following initial sucker densities, whereas Steneker (1974) suggested that 6 000 stems/ha at three years would be sufficient. A ten year study of aspen regeneration in southwestern Colorado (Crouch 1986) revealed a substantial decline in stand density with 74 000 stems/ha one year post-harvest, 17 000 stems/ha at six years post-harvest, and 531 stems/ha at ten years post-harvest.

Forage production also increases following harvesting. Bartos and Mueggler (1982) found a 1500 kg/ha increase at three years post-harvest compared to uncut mature aspen stands. DeByle (1976) found similar trends with a 350-450 kg/ha increase in forage production within one year after harvesting.

In contrast to previous discussion, several studies have reported poor aspen regeneration (Zasada and Schier 1973, Crouch 1986, Bates et al. 1990, Shepperd 1990). Reduced soil porosity and organic matter removal are commonly associated with loss of forest productivity (Powers et al. 1990). For example, Alban et al. (1994) reported that an 80% reduction in forest floor thickness and a 22% increase soil compaction within a 0-10 cm depth significantly reduced biomass and height of two-year-old aspen suckers in northern Minnesota. Weingartner (1980) found scarification increased suckering but reduced height and diameter of aspen stems. Too much skidding traffic may damage the shallow roots and reduce suckering (Jones 1976); this reduced regeneration is associated with increased rutting and soil scarification. A number of studies (Maini and Horton 1966, Jones 1976, and Bella 1986) have also shown reduced suckering and stem vigor with excessive slash conditions. Jones (1976) found few or no suckers associated with slash piles, log deckings, main skid-trails, and haul roads.

There is a critical need to assess the impacts of forest harvesting on aspen regeneration. This study was conducted to test the hypothesis that no relationship existed between skidding intensity and aspen regeneration or forage supply. This study also tested the hypothesis that decking disturbances had no effect on aspen regeneration and forage supply.

EXPERIMENTAL AREA:

Location

The experimental area was located 15 miles north of Nojack, Alberta, west of Highway 751 (Section 19-21, 28-30, Range 11, Township 056 West of the fifth Meridian).

Climate

Wide distribution of aspen across North America indicates that it is adaptable to a range of climatic and microsite conditions. Cold continental and boreal climates are ideal for aspen growth, as aspen has a high resistance to frost and freezing conditions without snow cover (Haeussler and Coates 1986). Aspen is generally adapted to well-drained uplands. In addition to its relatively low water demands, aspen stands and emerging suckers are shade intolerant, requiring full sunlight for optimal stand growth and survival.

Geology and Soils

Parent material, deposited by continental ice sheets, was early tertiary till of Paskapoo Formation origin (Alberta Energy and Natural Resources 1978). This geological formation was characterized by horizontally bedded, medium to weakly cemented sandstone, soft shale beds, coal, and tuff. The landscape was characterized by sinuous, narrow till plains elevated between 2800 to 3200 feet Above Sea Level (ASL) and was overlain by a shallow, discontinuous outwash and slopewash deposit material. The landscape topography was moderately well drained with undulating (2-5% slope) to moderate rolling (9-15%) slope. Soils consisted of orthic gray luvisol, clay loams from the Hubalta soil series. McNabb (1994) showed an average bulk density of 1.18 Mg m^{-3}, within the 0-10 cm soil depth, within these soil types. These heavy clay soils have low organic matter and available plant nutrients, such as nitrogen and potassium, creating poor to fairly good arable soil (Twardy and Lindsay 1971).

Vegetation

The experimental area was situated in the Lower Boreal Cordilleran Ecoregion and the Southern Alberta Uplands Ecodistrict (Strong and Leggat 1992). Prior to harvesting, the area was dominated by *Populus tremuloides-Populus balsamifera/Alnus crispa/Calmagrostis canadensis* situated along midslope positions. Lower, moister landscape positions contained *Populus tremuloides- Populus balsamifera/Alnus tenuifolia-Alnus crispa/Calamagrostis canadensis*, while drier uplands produced *Populus tremuloides-Populus balsamifera/Fragaria virginiana/Calamagrostis canadensis* (Willoughby 1994). Average biomass production was 1459 kg/ha, although a high cover of alder in the understory limited livestock use (Sundquist et al. 1997).

Forest Harvesting

The forest harvesting system included clear-cutting with full-tree skidding in alternating cut-and-leave blocks on a two-pass system. Weyerhaeuser Canada Ltd. supervised the logging operation according to the Alberta Timber Harvesting Planning and Operation Ground Rules (1994) and the Weyerhaeuser Annual Operating Plan. Logging services where provided by Art Peyton Logging Ltd.

Harvesting equipment

Falling	2 - 618 Timberjack Feller Bunchers (20" Harricana Head)
Skidding	3 - John Deere 748 Grapple Skidders, with low ground pressure, high floatation tires.

Delimbing	1 - 300 cat - 2200 Lim-mit Delimber 2 - 892 JD 2200 Lim-mit Delimber
Slashing	2 - Hood Self - Propelled
Loading	2 - Cat 300 Knuckle Boom Loaders
Road Const.	1 - Cat D7H c/w Ripper 1 - Cat D7G 1 - Champion 740 Grader 1 - 690 JD Excavator

(Weyerhaeuser 1996).

Full-tree skidding

The full-tree harvesting system restricted work at the stump to falling the tree by a feller-buncher. Trees were forwarded by a four-wheel drive, rubber-tire grapple skidder from the stump to the decking site for limbing and cutting into shorter logs (2.6 m) (Zasada and Tappeiner 1969a, Weyerhaeuser 1996). Skidding created a series of long narrow forest trails (skid-trails) from stump to decking sites; repeated use of skid-trails removed standing vegetation and increased soil exposure.

Soil disturbance

Grapple skidders are equipped with large rubber tires as a precaution against extensive soil compaction (Weyerhaeuser 1996). Because the schedule for summer harvesting is influenced by site specific weather and soil moisture conditions, areas sensitive to soil degradation or site disturbances were identified and restricted from harvest. As a result, logging operations were terminated after extended periods of moisture as intensive traffic on moist soils were extremely sensitive to compaction (Weyerhaeuser 1996).

Slash disposal

Following skidding, further processing consisted of limbing, cutting, and stacking of the aspen logs along the road side or decking site. Heavy slash accumulations, created from the limbing process, were piled and burned, while lighter slash accumulations were spread throughout the decking area (Weyerhaeuser 1996).

Logging road

Road construction occurred in two-phases. Preharvest road construction involved excavating upper organic layers and vegetation (graders level and compact the mineral layers) which formed a hardpan road adequate for large flat-bed trucks to travel upon. After harvest, roads were deep ripped and scattered with forest floor top soil and accumulated woody debris from the limbing process.

METHODOLOGY:

Measurements

Aspen stem characteristics including, aspen stem density, height, and diameter were measured at one and two years post-harvest in June (spring) and September (fall). The number of aspen and populus (aspen + balsam poplar) suckers within a 2 m^2 quadrat was recorded in stems/m^2. Due to the prominence of balsam poplar within the study area, populus (aspen and balsam) density was recorded to measure total suckering potential for each treatment. Height of the tallest or the average of the five tallest aspen stems was measured in 1995 and 1996 respectively. Stems were measured in centimeters from ground level to the tip of the terminal bud. Vernier calipers were used to measure basal diameter at ground level (millimeters), of the tallest or the average of the five tallest aspen stems in 1995 and 1996 respectively. Stem height and diameter measurements were also recorded separately for aspen and populus stems.

Two variables adapted from Bates et al. (1993) were utilized to identify regeneration response to harvesting: (*i*) total aspen stem length, a variable that integrated both stem density and height by multiplying average plot stem height with average plot stem density (stems/m^2), and (*ii*) total populus stem length to account for the occurance of aspen and balsam poplar.

Vegetative biomass was measured for each forest harvest disturbance treatment at one and two years post-harvest. At the peak of the growing season (end of July) vegetative biomass was clipped to within 1 cm of the ground surface within a 0.5 m^2 quadrat randomly located within each harvesting treatment. Samples were separated into graminoid, shrub and forb, aspen, and balsam poplar for each plot, dried, weighed, and recorded in grams/m ^{2}.

Data Analysis

The basic experimental design for aspen stem characteristics (stem density, height, and diameter) was a randomized complete block with six blocks and eight harvesting treatments. Because repeated measurements were made from the permanent plots over two years (1 and 2 years post-harvest) and two seasons (spring and fall) the model for analyzing the effect of harvesting treatments on aspen stem characteristics was:

$$Y_{ij} = \mu + B_i + T_j + E_{ij}.$$

Where Y_{ij} is the set of year and season measurements made on the ith block and on the jth treatment, and μ, B_i, T_j, and E_{ij} are vectors of overall mean, block effects, treatment effects, and random errors respectively.

The experimental design for forage production was a split plot with six blocks, eight harvesting treatments as the main plot treatments and two years as the subplot treatments. The statistical model was:

$$Y_{ijk} = \mu + B_i + T_j + e_{ij} + Y_k + TY_{jk} + E_{ijk}.$$

where:
Y = Dependent variable.
B = Block.
T = Harvesting treatment.
e = Error term for testing block and treatment effects.
Y = Year.
TY = Treatment by year interactions.
E = Error term for testing TY.

Computations for analysis were made using the GLM procedure of SAS (SAS Institute, Inc. 1989). Skid disturbance treatments were (no-skid = 0, light skid = 1, moderate skid = 3, heavy skid = 5, very heavy skid = 7) based on the relative soil surface disturbances created with increased traffic intensity. Trend analysis was based on fitting linear or quadratic models between skid disturbances and dependent variables. The Dunnett Test was used to compare decking disturbances (slash, burn, and road) with the no-skid treatment.

Analysis of covariance was conducted utilizing parent stand density as a covariate for aspen regeneration within each 2 m^2 permanent plot. Various formulae were used relating surrounding 50 m^2 suckering potential to individual plots, however none of the covariates significantly improved goodness of fit ($p < 0.05$).

RESULTS:

Due to the relatively low variation of temperature and precipitation within the experimental area, differences in weather conditions were considered negligible between one and two year post-harvest (Figure 3.1). The experimental area has a continental climate characterized by warm summers and cold winters. Average temperature during the 1995 and 1996 growing seasons was 12.8°C, with July the warmest month (16.2°C) and September the coolest month (9.2°C). Average precipitation was 76 mm, with June receiving the highest precipitation (106 mm) and September the least (33 mm).

A summary of aspen regeneration relative to harvesting disturbances at one and two years post-harvesting is presented in Table 3.1. Although no statistical analysis was conducted, values provide an indication of regeneration throughout the experimental area. Although stem vigor and biomass production increased from the first to second year post-harvest there was a 20% and 40% decline in stem density between one and two years post-harvest on skid-trails and decking sites respectively. Skidding traffic did not effect 28% of the harvested area, although 63% of the harvested area was effected by some level of skidding disturbance. At two years post-harvest there were substantial stem density (38 000 – 54 000 stems/ha) for 84% of the harvested area (no-skid, light, moderate, and heavy skid), the remaining 16% (very heavy skid, slash, burn, and road) were lower (17 000 – 3 600 stems/ha). Stem vigor, and biomass production were substantial on 72% of the harvested area (no-skid, light, and moderate skid), whereas the remaining 28% (heavy skid, very heavy skid, slash, burn, and road) had much poorer measures of stem vigor and biomass production.

Stem Characteristics

Anova tables for aspen stem characteristics are presented in Appendices 7.1 and 7.2 for skidding intensity and decking disturbances respectively. Aspen stem density peaked at moderate skidding intensity and declined with lower and higher levels of skidding at one and two years post-harvest (Figure 3.2a). Sucker mortality was evident as stem density declined from 5.1 stems/m^2 at 1 yr. post-harvest to 3.9 stems/m^2 at 2 yrs. post-harvest. Mortality was also evident within the growing season as density declined from 4.9 stem/m^2 in the spring to 3.8 stems/m^2 in the fall. Stem density was also reduced by decking disturbances at one and two years post-harvest, and from spring to fall (Figure 3.2b).

Aspen stem height peaked at light skidding intensity and declined with no and increased skidding (Figure 3.3a). Stem height increased from 68.6 cm at one year post-harvest to 72.9 cm at two years post-harvest, from 63.7 cm at spring to 74.7 cm at fall. Decking disturbances reduced stem height, although stem height increased from 39.4 cm at spring to 44.6 cm at fall (Figure 3.3b).

Total aspen stem length also peaked at moderate skidding and declined with lower and higher levels of skidding at one and two years post-harvest (Figure 3.4a). Total stem length declined from 418 cm at 1 year post-harvest to 322 cm at 2 years post-harvest, from 404 cm at spring to 377 cm at fall. A reduction in total stem length was also evident on decking disturbances at spring and fall (Figure 3.4b).

To account for populus (aspen + balsam poplar) stem characteristics, total populus stem length was assessed relative to skid intensity. Total populus stem length peaked at light skidding and declined at no and increased skidding at one and two years post-harvest (Figure 3.5a). Populus stem length declined from 527 cm at one year post-harvest to 417 cm at two years post-harvest, from 441 cm at spring to 410 cm at fall. A reduction in populus stem length was also evident on decking disturbances at one and two years post-harvest, and at spring and fall (Figure 3.5b).

Aspen stem diameter declined with increased skidding intensity (Figure 3.6a). Stem diameter increased from 7.2 mm at one year post-harvest to 10.2 mm at two years post-harvest. Decking disturbances reduced aspen stem diameter at both one and two years post-harvest (Figure 3.6b). Stem diameter increased from 5.0 mm at one year post-harvest to 6.8 mm at two years post-harvest.

Forage Production

Anova tables for forage production are presented in Appendices 7.3 and 7.4 for skidding intensity and decking disturbances respectively. At one year post-harvest graminoid biomass declined with increased skidding intensity, whereas skidding intensity had no effect on graminoid biomass at two years post-harvest (Figure 3.7a). Biomass production increased from 72 grams/m^2 at one year post-harvest to 112 grams/m^2 at two years post-harvest. Decking disturbances reduced graminoid biomass at both one and two years post-harvest, although biomass increased from 10 grams/m^2 at one year post-harvest to 40 grams/m^2 at two years post-harvest (Figure 3.7b).

Shrub and forb biomass was consistent across the skidding intensity gradient (Figure 3.8a). Slash did not reduce shrub and forb biomass at 2 years post-harvest, although burn and road disturbances reduced biomass at both one and two years post-harvest (Figure 3.8b). Shrub and forb biomass increased from 30 grams/m^2 at one year post-harvest to 88 grams/m^2 at two years post-harvest.

Aspen biomass peaked at light skidding and declined at no and increased skidding intensities at both one and two years post-harvest (Figure 3.9a). Biomass increased from 48 grams/m^2 at one year post-harvest to 94 grams/m^2 at two years post-harvest. Decking disturbances reduced aspen biomass when averaged across one and two years post-harvest (Figure 3.9b).

Total biomass peaked at light skidding intensity and declined with no and increased skidding intensities when averaged across one and two years post-harvest (Figure 3.10a). Decking disturbances reduced total biomass at both one and two years post-harvest (Figure 3.10b).

DISCUSSION AND MANAGEMENT IMPLICATIONS:

Skidding

Trend analysis allowed aspen regeneration to be examined across a linear skidding intensity gradient characterized by increased ground scarification and soil compaction. Relationships created between dependent variables and skidding intensity identified optimal levels of skid traffic on aspen regeneration.

Light skidding created the most productive aspen suckers with stem height, diameter, populus stem length, and aspen biomass declining with increased skidding intensity. Lower stem density created by light skidding enabled individual stems to increase in size (Pyke and Archer 1991). Light skidding created a soil-rooting environment that limited the number of emerged stems, which undoubtedly created optimal conditions for stem growth.

Moderate skidding disturbance maximized aspen stem density and total aspen stem length at both one and two years post-harvest. Moderate skidding disturbance created soil surface conditions, through the removal of litter and woody debris, for enhanced soil rooting temperatures that stimulated aspen suckering. Disturbance at this level was, apparently, not severe enough to negatively impact the aspen roots closest to the soil surface. However, due to high stem densities, stem height, diameter, and aspen biomass production were less than optimal.

Moderate levels of skidding intensity produced optimal conditions for abundant aspen stem density and length, whereas an increased skidding intensity displayed negative impacts. Scarification and soil compaction from repeated skidding created a stress on the soil-rooting medium that caused a reduction in aspen regeneration. Increased scarification and soil compaction created by increased skidding intensities reduced aspen stem density, height, diameter, and biomass production. Bates et al. (1993) also found increased equipment traffic reduced aspen regeneration on summer harvested cut-blocks.

Harvesting activities can affect the physiological and environmental variables that control suckering (Bates et al. 1993). Root destruction, soil compaction, scarification, forest floor displacement, and understory destruction are factors that can negatively affect aspen regeneration. It is well documented, however, that mechanized harvesting can also play a positive role in aspen regeneration by reducing competing vegetation and increasing soil temperature, thus optimizing site conditions for suckering (Bella 1986, Bella and Defranceschi 1972, Maini and Horton 1966, Perala 1972, Steneker 1974, Zasada and Tappeiner 1969b). If these positive effects are to benefit suckering, a proper balance must be achieved between ground surface clearing of litter and woody debris and rooting medium disturbance created by forest harvesting. This proper balance was achieved by light to moderate levels of skidding intensity.

Higher levels of skidding intensity negatively impacted aspen regeneration. Heavy and very heavy skidding were associated with increased forest floor displacement and soil compaction, and either directly or indirectly affected the energy flows from the soil and/or within the aspen parent root system. Although the cause and effect relationships remain unclear, the association of intense skidding and reduced aspen regeneration needs to be addressed in forest management planning.

Decking

Severe site disturbances created within the project decking area reduced aspen stem density, height, diameter, total stem length, as well as aspen and forage biomass production. The harvesting activities of bucking, limbing, piling, and burning of slash as well as the deep tillage of haul roads created site conditions that may never naturally regenerate aspen stems. Temporary haul road disturbances severely degrade soils by compaction and remoulding (McNabb 1994). However, the tillage of haul roads, and pull back of soil and woody debris, is a rehabilitation process, commonly practiced, to establish conifer seedlings since the aspen parent root system was removed with the soil surface horizons. Despite these efforts, successful aspen seedling establishment is rare due to the demanding seed germination requirements (Maini 1968). However, there has been success in establishing conifer seedlings on tilled haul roads (McNabb 1994). Burn sites, within the experimental area were also reduced to aspen seedling establishment. The removal of the soil surface horizons and parent roots through intensive burning, to remove excess woody debris, eliminated natural aspen regeneration by root suckering.

Slash microsites created unfavorable conditions for aspen regeneration. Woody debris on the soil surface restricted soil-rooting temperatures required for sucker development (Maini and Horton 1966, Steneker 1974). The prominence of shrub and forb biomass further restricted aspen stem development. A conscious effort to remove or burn slash, created from the limbing of logs, would reduce unfavorable microsites and thereby increase potential suckering and stem vigor.

Any type of disturbance that removes the parent aspen stand without killing the roots will stimulate suckering. The number and vigor of suckers, however, is affected by the physiological and environmental conditions present at the time of the disturbance, and by the impact of the disturbance on root and site conditions (Bates et al. 1988).

Vegetative competition

Following harvest disturbance, environmental and site conditions created the conditions for vegetation establishment. With vegetation establishment, intraspecific and interspecific competition for energy and soil nutrients affected the survival of aspen stems.

Aspen stem mortality between one and two years post-harvest and between spring and fall, was a clear indication of natural thinning created by competition for limited resources of sunlight and soil nutrients. Natural thinning of an emerging aspen stand effectively controls sucker density, as less vigorous suckers die-off within the first two years following harvesting (Graham et al. 1963, Pollard 1971, Smith et al. 1972, Jones 1975). It is not until the aspen suckers develop a low stem to leaf ratio and begin actively photosynthesizing that they produce their own root system and thereby become self sufficient (Schier 1981). The self-thinning principle, where plant biomass is related to initial plant density, and the dynamic process of density-dependent mortality, have been utilized in forest management (Drew and Flewelling 1977) and plant ecology (White

1981, and Westoby 1984). The decline in aspen stem density coincided with increased aspen vigor and biomass, as well as grass and forb biomass production, further illustrating intraspecific and interspecific competition.

The development of an aspen stand has been found to decrease grass production (Friesen et al. 1965). Aspen suckers emerging from parent roots have a competitive advantage, as root carbohydrate reserves sustain emerging shoots until leaves develop and photosynthesis begins (Schier 1981, Schier et al. 1985). Grass, shrub, and forb production on areas that experienced heavy skidding intensities, however, may affect long-term sustainable aspen production. Relatively low aspen biomass and high grass biomass may restrict aspen growth or subsequent emergence. A controlled greenhouse study by Bailey and Gupta (1973) found aspen competition reduced grass yield by 26 percent, whereas grass competition reduced aspen yield by 50 percent. However, the effect of grass competition on aspen regeneration within a clear-cut harvested situation is unknown. Further control of subsequent aspen suckering, following initial aspen stem development, will likely be suppressed by the dominant aspen stems through apical dominance. Although it is difficult to project, it is clear that antagonistic plant interactions will affect plant establishment and persistence (Pyke and Archer 1991).

Forage Production

Increased skidding intensity reduced forage production. However, it was quite clear that skidding disturbances provided site conditions conducive to abundant forage production, averaging 3560 kg/ha and 3160 kg/ha at one and two years post-harvest respectively. Decking disturbances produced considerably less forage than skidded areas at both one and two years post-harvest, averaging 1692 kg/ha and 1758 kg/ha respectively likely due to a lack of seed. The displacement of topsoil, within burn and haul road disturbances, alters the long-term productivity of these sites (McNabb 1993). With the exceptions of the noted reductions in forage, overall conditions following harvesting were favorable to abundant forage production for domestic and wildlife use.

Regeneration Standards

Several attempts have been made to evaluate initial stem densities on long-term yields. Recommended minimum density and stocking levels vary and are difficult to prescribe due to the high mortality induced by competition at a given site (Bella and DeFranceshi 1972). Regeneration requirements are based on provincial stocking standards designed to ensure sustainable timber production. Deciduous standards at five years post-harvest require 80% of plots surveyed to be stocked with approximately 7 500 stems/ha with an average stem height of 160 cm (Anonymous 1996). These standards vary according to sub-region, drainage class, and eco-site.

The natural mortality between one and two years post-harvest and the low growth rates may create concerns on long-term stand productivity (Table 3.1). Aspen stem densities found within the study area showed an incremental loss of 11 000 stems/ha between the first and second years post-harvest, averaged on a percentage basis, on skid trail disturbances, and 4 000 stems/ha on decking disturbances. The decline in stem density coincided with an incremental increase in stem vigor and biomass between the first and second years post-harvest. However, the increase in aspen stem height was minimal due to a major infestation of leaf and twig blight (*Venturia macularis* Fr.), a fungal pathogen, which can severely disfigure and affect growth of young aspen shoots (Hiratsuka et al. 1995).

At two years post-harvest 84% of the harvested area (no-skid, light, moderate, and heavy skid) produced abundant stem densities; however, the remaining 16% (very heavy skid, slash, burn, and road) of the cut-block produced lower aspen stem densities which is of serious concern. Stem vigor and production is also a concern with intense skidding (heavy and very heavy) and decking disturbances, which incorporated 28% of the harvested area. It is important to further note aspen regeneration measurements were recorded only for upland microsites (51% of the harvested area) while microsite depressions (49% of the harvested area) were not recorded due to the lack of aspen regeneration. Acknowledging half the harvested area as unsuitable for aspen suckering combined with the effects of intense skidding and decking disturbances creates serious concerns for achieving provincial regeneration standards.

CONCLUSIONS:

A quadratic relationship was established between skidding intensity and aspen stem density, stem height, total stem length, aspen biomass production, and total biomass production. A linear relationship was established between skidding intensity and aspen stem diameter, no relationship was established between skidding intensity and grass biomass production. Aspen regeneration and forage production were maximized with light to moderate skidding disturbance regimes and decreased with no-skid and increased skidding intensity. Although the skidding intensity regime incorporated 91% of the cut-blocks, only 7% of the skidded area severely reduced aspen regeneration and forage production. Decking disturbances significantly reduced aspen regeneration and forage production. Although only 9% of the cut-block area, when combined with the effects of very heavy skidding, 16% of a given cut-block has potentially jeopardized early establishment of natural aspen regeneration on upland microsites.

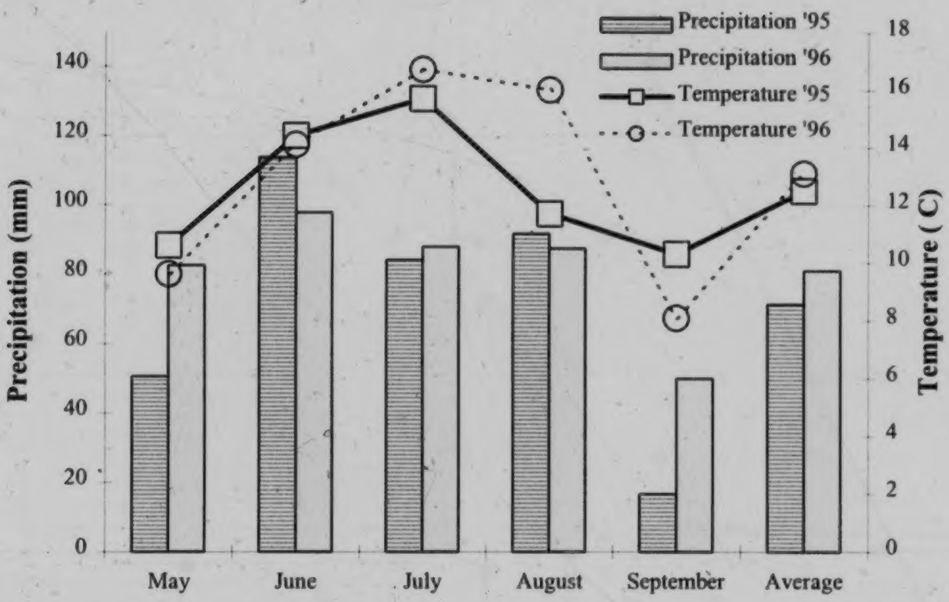

Figure 3.1 Average monthly precipitation and temperature during the 1995 and 1996 growing seasons at Cold Creek Ranger Station Nojack, Alberta.

Table 3.1 Aspen regeneration as measured in September on upland microsites relative to specific harvesting disturbances, at one and two years post-harvest.

Harvesting disturbance	**Aspen density (stems/ha)**		**Stem height (cm)**		**Stem diameter (mm)**		**Biomass (kg/ha)**		**Cut-block area (%)**
Year	1	2	1	2	1	2	1	2	
No-skid	50 000	38 000	84	89	8	11	476	864	28
Light	54 000	45 000	85	92	8	11	798	1 938	30
Moderate	65 000	54 000	78	86	7	10	696	1 088	14
Heavy	61 000	38 000	65	66	8	9	272	518	12
Very heavy	23 000	17 000	47	53	6	8	196	268	7
Slash	12 000	10 000	35	48	5	8	60	100	3
Burn	11 000	3 600	8	14	2	4	12	4	1
Road	8 900	4 800	15	16	4	4	22	30	5
Cut-block	52 000	41 000	77	83	8	10	562	1150	91
Decking	10 000	6 000	23	26	4	5	33	50	9

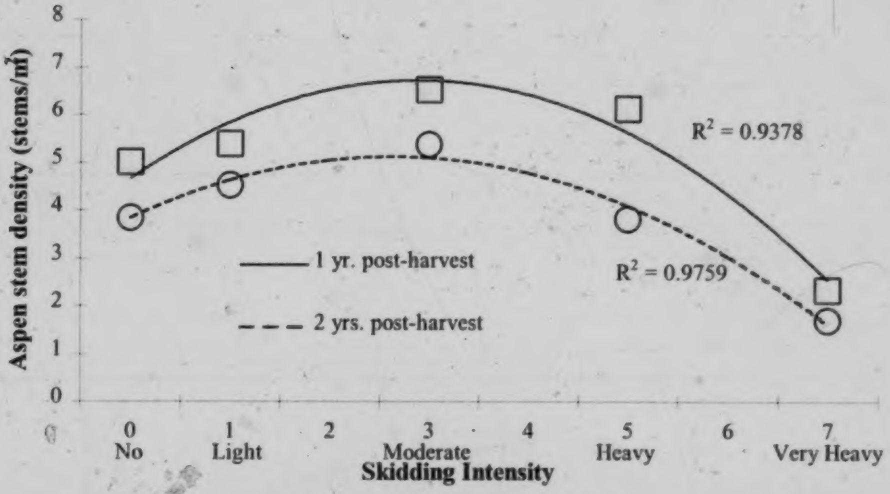

Figure 3.2a The relationship between aspen stem density and harvest skidding intensity. Both the linear and quadratic effects of skidding intensity on 1-yr post-harvest aspen stem density, averaged over seasons, were significant ($p<0.05$). Only the quadratic effect of skidding intensity on 2-yrs post-harvest density, averaged over seasons, was significant. Stem density, averaged over seasons, decreased by 1.2 stems/m^2 between the first and second years after harvest. Stem density, averaged over years, decreased by 1.1 stems/m^2 between the spring and fall. No other interactions were significant.

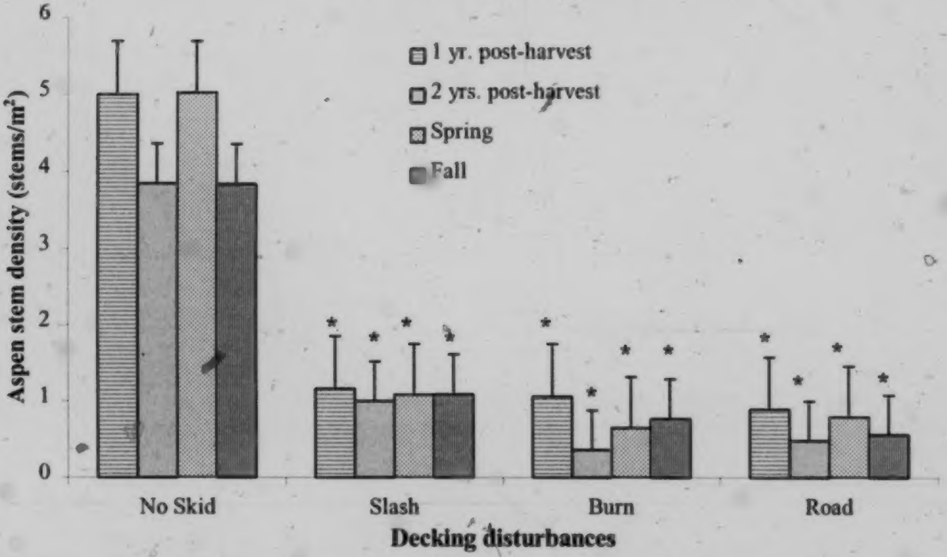

Figure 3.2b Comparisons of aspen stem density between no-skid and decking disturbances. Decking treatments were significantly different (*) from no-skid treatment ($p<0.05$). No other treatment effects or interactions were significant. Vertical bars represent 95% confidence intervals of the means.

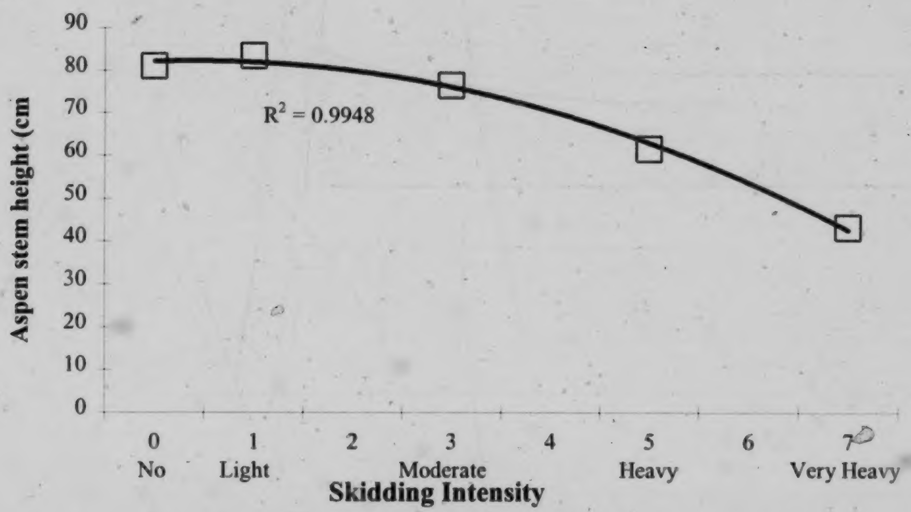

Figure 3.3a The relationship between aspen stem height and harvest skidding intensity. Both the linear and quadratic effects of skidding intensity on stem height, averaged over years (1 and 2 yrs. post-harvest) and seasons (spring and fall), were significant ($p<0.05$). Stem height, averaged over seasons, increased by 4.3 cm between the first and second years. Height, averaged over years, increased by 11.0 cm between spring and fall. The year and season interaction effect was significant, with the differences between seasons being 7.4 cm greater in the second year than in the first year.

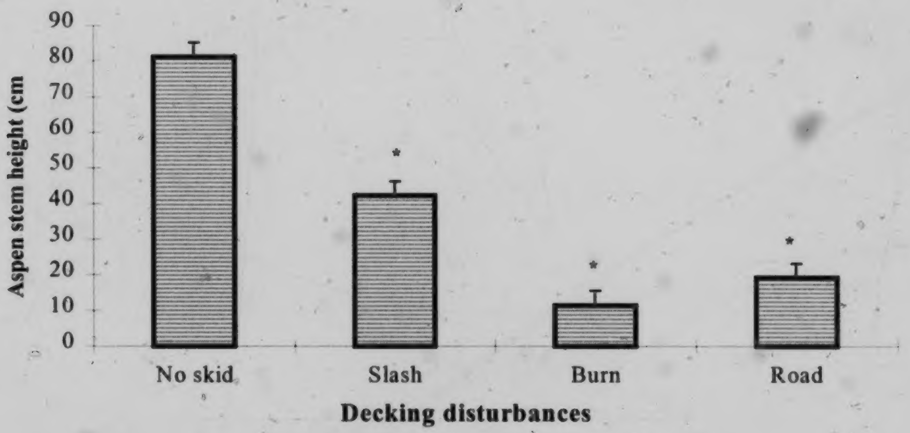

Figure 3.3b Comparisons of aspen stem height between no-skid and decking disturbances. Decking treatments, averaged across years (1 and 2 yrs. post-harvest) and seasons (spring and fall), were significantly different from the no-skid treatment ($p<0.05$). Stem height, averaged over years, increased by 5.2 cm between the spring and fall seasons. No other treatment effects or interactions were significant. Vertical bars represent 95% confidence intervals of the means.

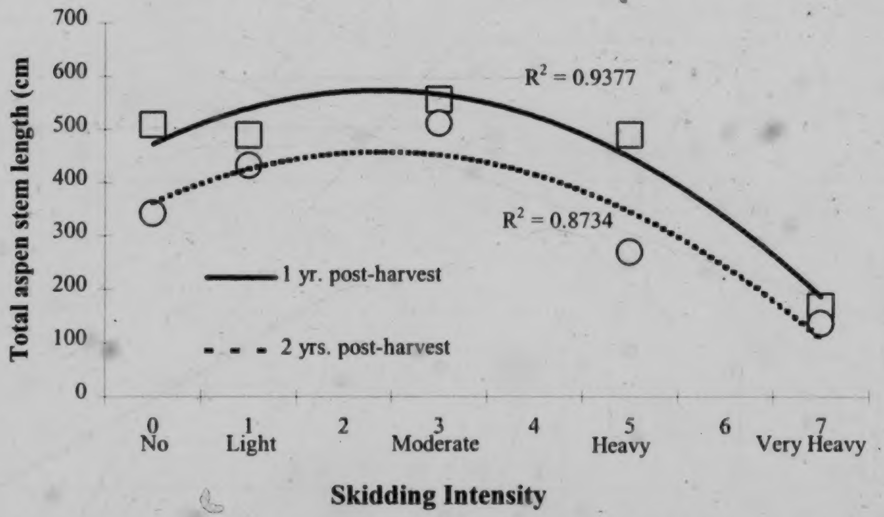

Figure 3.4a The relationship between total aspen stem length and harvest skidding intensity. Both the linear and quadratic effects of skidding intensity on aspen stem length, averaged over seasons (spring and fall), were significant ($p<0.05$). Stem length, averaged over seasons, decreased by 96 cm between the first and second years. Length, averaged over years, decreased by 26 cm between spring and fall. No other interactions were significant.

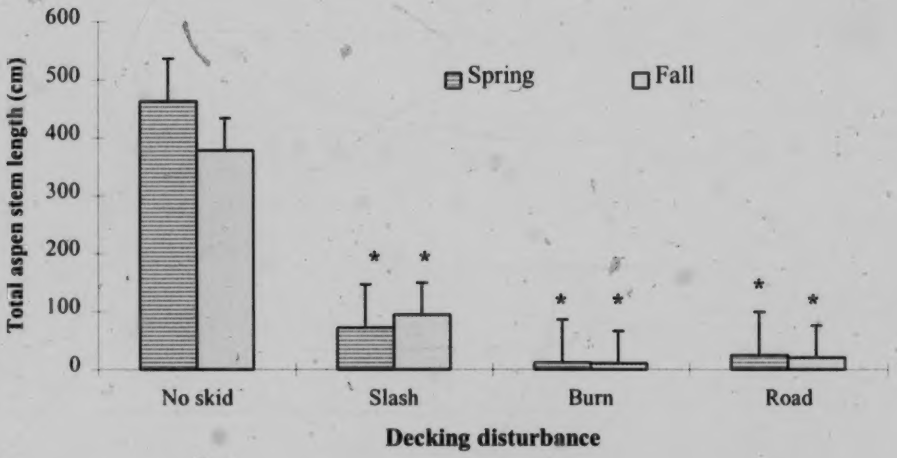

Figure 3.4b Comparisons of total aspen stem length between no-skid and decking disturbances. Decking treatments, averaged over years (1 and 2 yrs. post-harvest) were significantly different (*) from no-skid treatment ($p<0.05$). No other treatment effects or interactions were significant. Vertical bars represent 95% confidence intervals of the means.

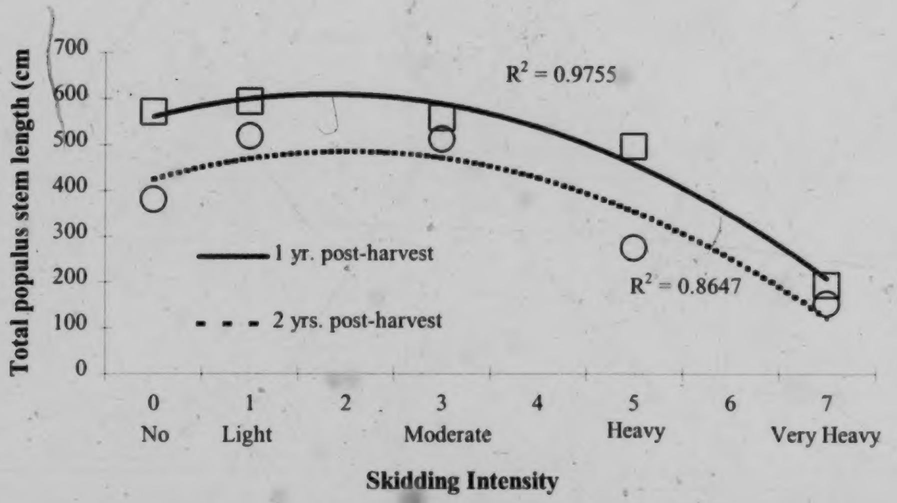

Figure 3.5a The relationship between total populus stem length and harvest skidding intensity. Both the linear and quadratic effects of skidding intensity on populus stem length, averaged over seasons (spring and fall), were significant ($p<0.05$). Stem length, averaged over seasons, decreased by 110 cm between the first and second years. Length, averaged over years, decreased by 31cm between spring and fall. No other interactions were significant.

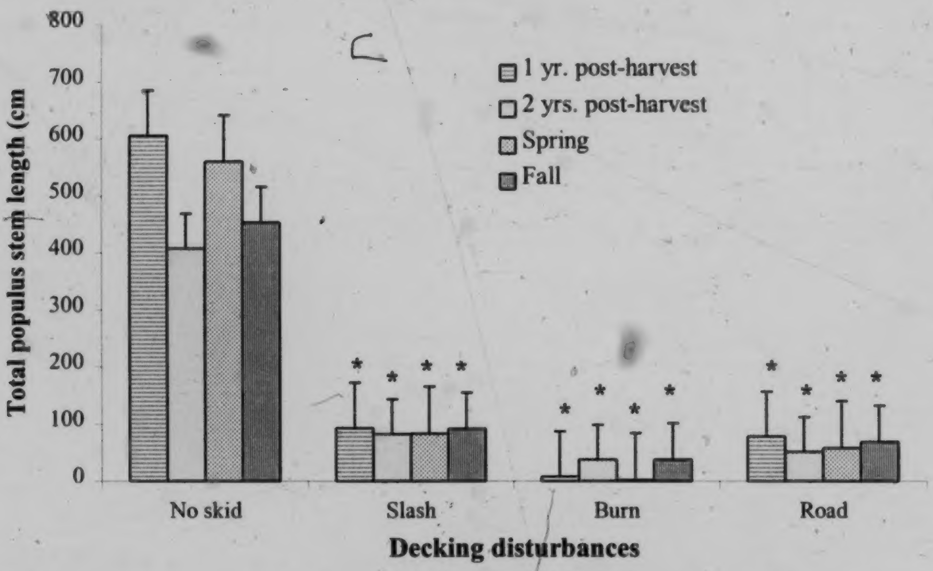

Figure 3.5b Comparisons of total populus stem length between no-skid and decking disturbances. Decking treatments were significantly different (*) from the no-skid treatment ($p<0.05$). No other treatment effects or interactions were significant. Vertical bars represent 95% confidence intervals of the means.

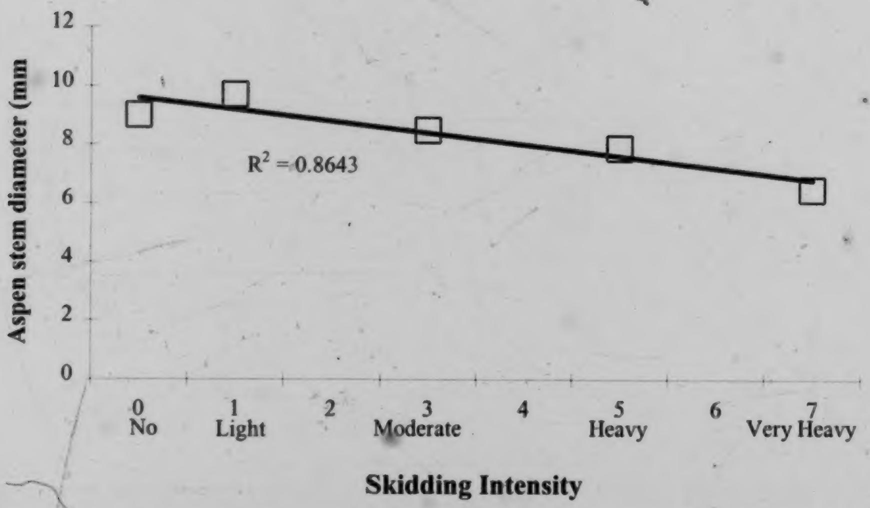

Figure 3.6a The relationship between aspen stem diameter and harvest skidding intensity. A linear effect of skidding intensity on aspen stem diameter, averaged over years (1 and 2 yrs. post-harvest) and seasons (spring and fall), was significant ($p<0.05$). Stem diameter, averaged over seasons, increased by 3.0 mm between the first and second years. No other interactions were significant.

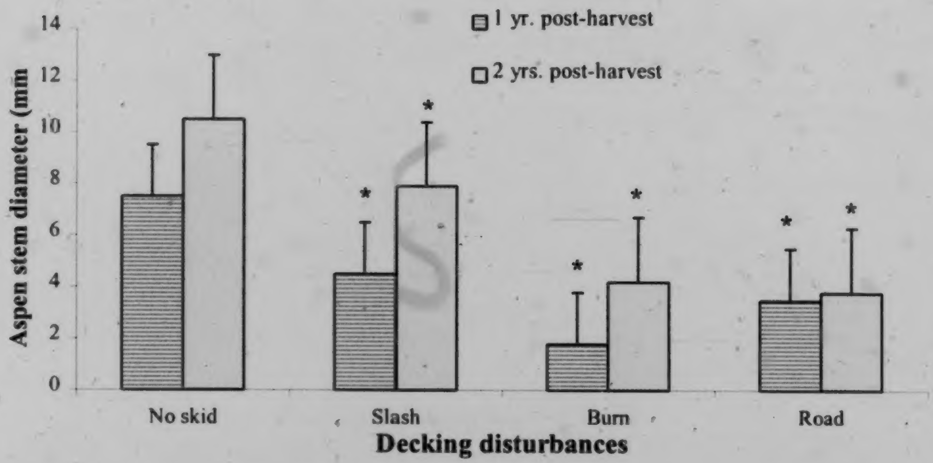

Figure 3.6b Comparisons of aspen stem diameter between no-skid and decking disturbances. Decking disturbances, averaged over seasons (spring and fall) were significantly different (*) from the no-skid treatment ($p<0.05$). Stem diameter, averaged over seasons, increased by 1.8 mm between the first and second years. No other treatment effects or interactions were significant. Vertical bars represent 95% confidence intervals of the means.

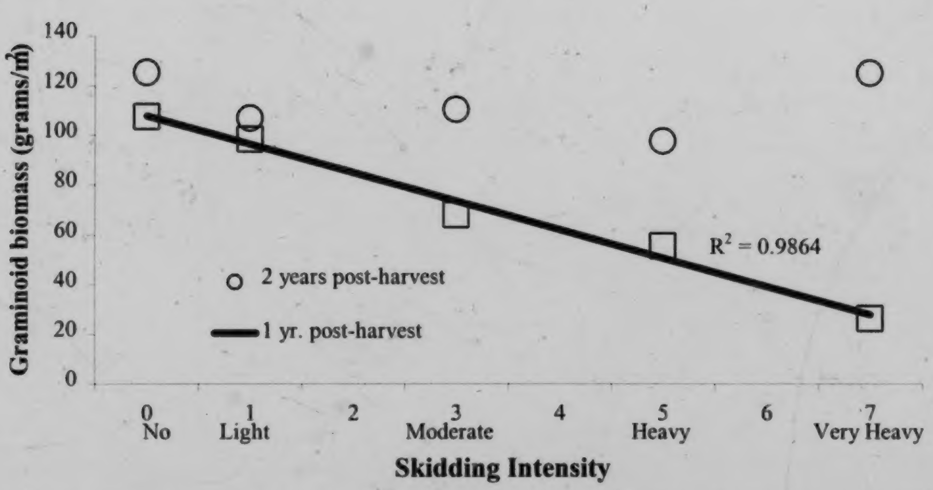

Figure 3.7a The relationship between graminoid biomass and harvest skidding intensity. The linear effect of skidding intensity on graminoid biomass, averaged over seasons, was significant at 1 yr. post-harvest, but not at 2 yrs. post-harvest ($p<0.05$). Graminoid biomass increased by 40 grams/m^2 between the first and second years after harvest ($p<0.05$). No other treatment effects or interactions were significant.

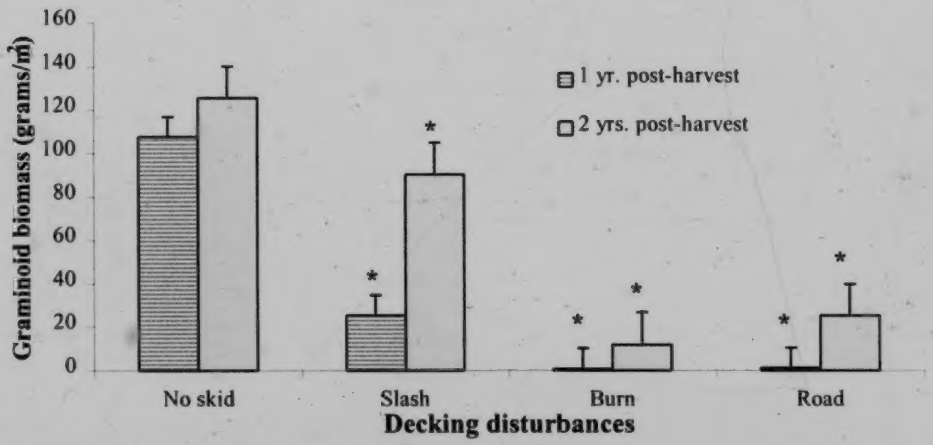

Figure 3.7b Comparisons of graminoid biomass between no-skid and decking disturbances. Decking disturbances were significantly different (*) from the no-skid treatment ($p<0.05$). Graminoid biomass increased by 30 grams/m^2 between the first and second years after harvest. No other treatment effects or interactions were significant. Vertical bars represent 95% confidence intervals of the means.

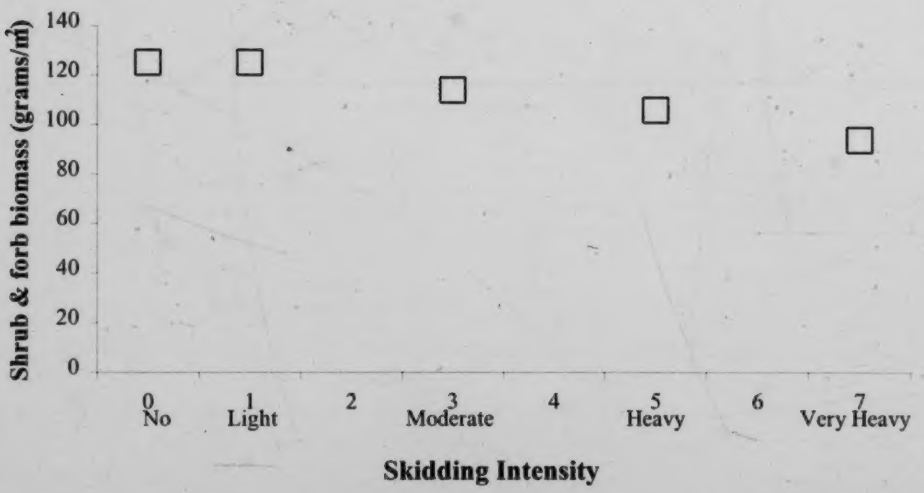

Figure 3.8a The relationship between shrub & forb biomass and harvest skidding intensity. There were no significant effects of skidding intensity, year, or season ($p<0.05$). No interactions were significant.

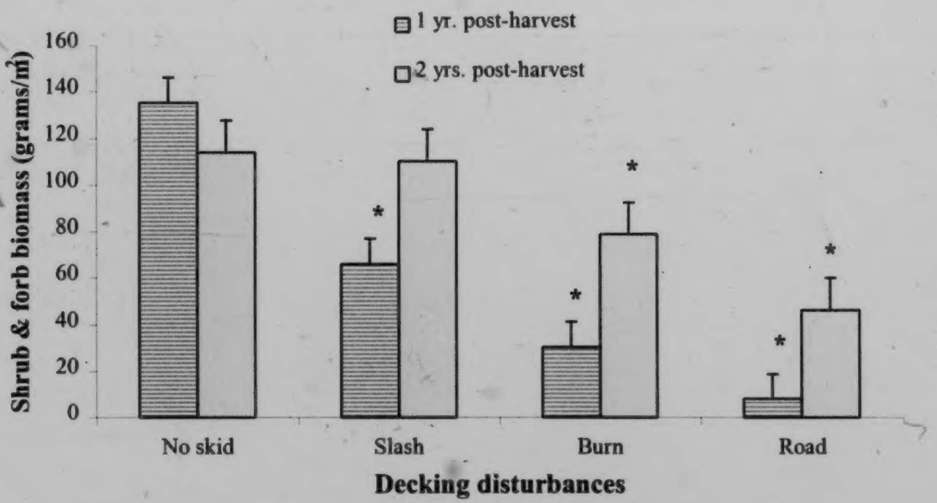

Figure 3.8b Comparisons of shrub & forb biomass between no-skid and decking disturbances. Decking disturbances were significantly different (*) from the no-skid treatment ($p<0.05$). Shrub and forb biomass increased by 28 grams/m^2 between the first and second years after harvest. No other treatment effects or interactions were significant. Vertical bars represent 95% confidence intervals of the means.

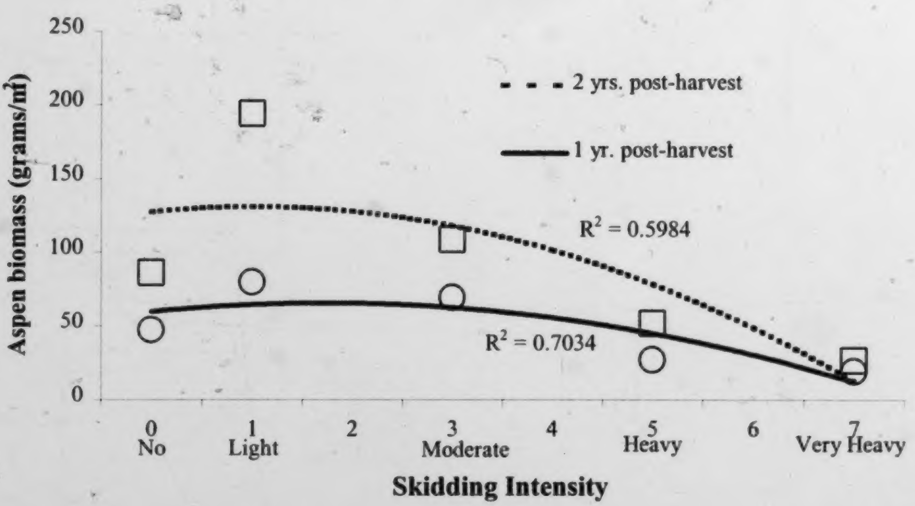

Figure 3.9a The relationship between aspen biomass and harvest skidding intensity. Both the linear and quadratic effects of skidding intensity on 1 yr. post-harvest aspen biomass, were significant ($p<0.05$). Only the quadratic effect of skidding intensity on 2 yrs. post-harvest biomass was significant. Aspen biomass increased by 22 grams/m^2 between the first and second years after harvest ($p<0.05$). No other interactions were significant.

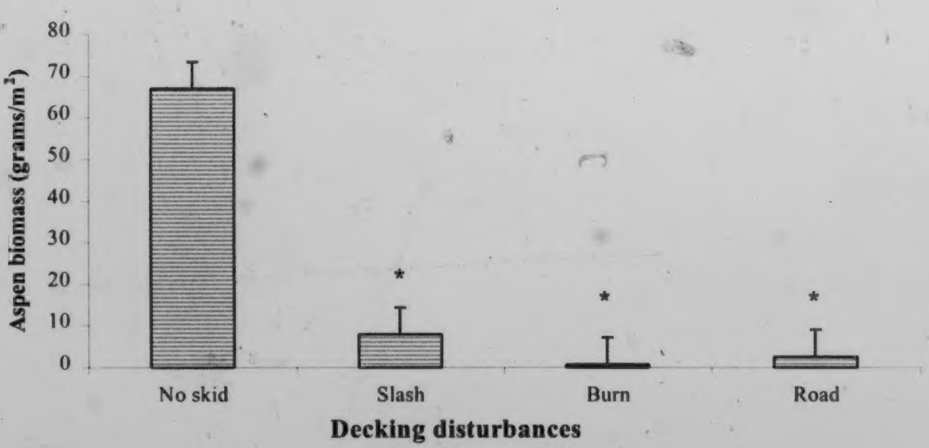

Figure 3.9b Comparisons of aspen biomass between no-skid and decking disturbances. Decking disturbances, averaged across years (1 and 2 yrs. post-harvest), were significantly different from the no-skid treatment ($p<0.05$). No other treatment effects or interactions were significant. Vertical bars represent 95% confidence intervals of the means.

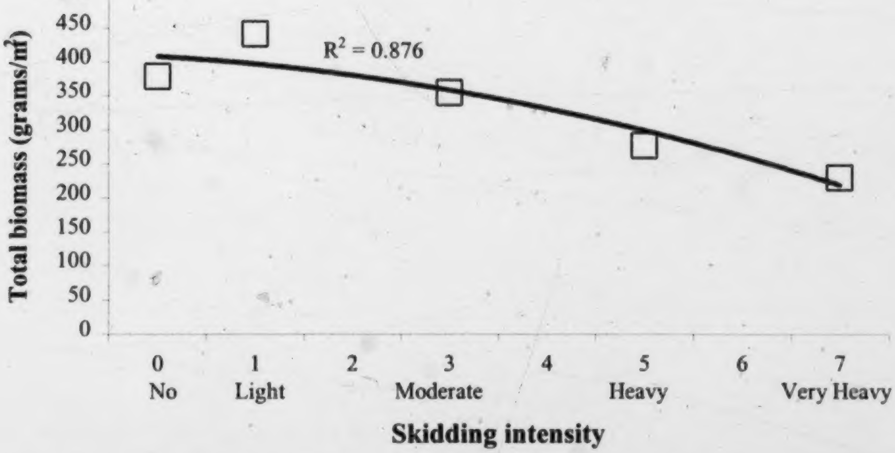

Figure 3.10a The relationship between total biomass and harvest skidding intensity. Both the linear and quadratic effects of skidding intensity on total biomass, averaged across years (1 and 2 yrs. post-harvest), were significant ($p<0.05$). No other treatment effects or interactions were significant.

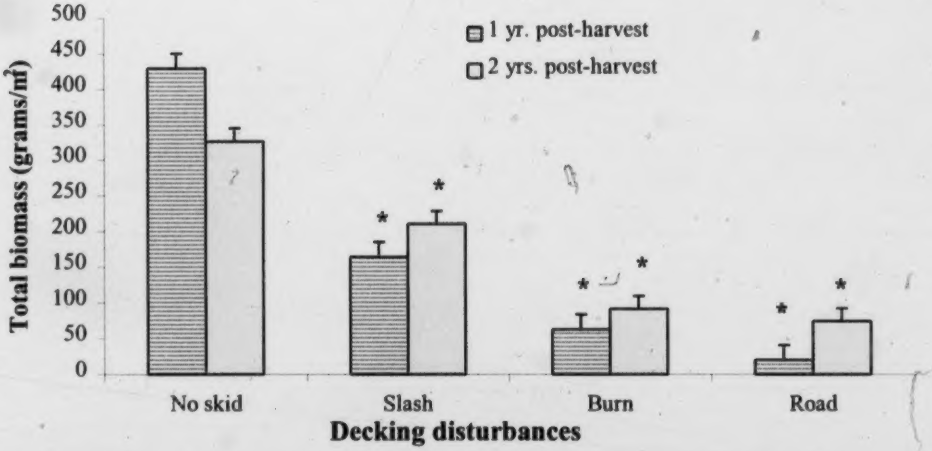

Figure 3.10b Comparisons of total biomass between no-skid and decking disturbances. Decking disturbances were significantly different (*) from the no-skid treatment ($p<0.05$). No other treatment effects or interactions were significant. Vertical bars represent 95% confidence intervals of the means.

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IV. EFFECT OF CATTLE UTILIZATION AND FOREST HARVESTING TECHNOLOGY ON ASPEN REGENERATION

INTRODUCTION:

Problem Analysis

Trembling aspen (*Populus tremuloides* Michx.) is the most widely distributed native tree species in North America (Jones 1985). In the Prairie Provinces, hardwood species such as trembling aspen and balsam poplar (*Populus balsamifera* L.) make up one-quarter of the 4327 million oven-dry tonnes of standing forest crop (Bonnor 1985). Alberta alone has over 6.8 million hectares of pure aspen stands which are affected by the multiple activities of forestry, oil, gas, domestic livestock, wildlife, watershed, and recreational use (Wheeler and Willoughby 1993). In north-central Alberta, harvesting of deciduous timber has expanded on three occasions since the 1980's to meet increasing consumer demands for oriented strand board, pulp, and chopsticks (Darrah 1991). Poplar forest communities within this ecoregion are important for commercial timber harvesting operations and provide substantial forage for livestock summer grazing.

Alberta Environmental Protection, Land & Forest Service, has issued Grazing Leases (GRL's) and Forest Grazing Licenses (FGL's) to livestock producers for summer grazing of aspen stands. Deciduous Timber Licenses (DTL's) have also been issued to Weyerhaueser Canada Inc. to harvest aspen timber within existing GRL's and FGL's. Current legislation gives timber companies access to remove standing timber on either a GRL or FGL grazing disposition, while Land & Forest Service presently functions to maintain sustainable timber and grazing benefits. This multiple use of aspen-covered lands necessitates investigation of the controversy affecting the timber and livestock industries.

Narrowly focused forestry and grazing interests create major confrontations between the two industries (Clark 1975, Kosco and Bartolome 1981). Conflicts often arise when one land use infringes upon, or is perceived to infringe upon, the responsibilities or rights of another. A lack of understanding of forest ecology and the complex interaction of timber, forage, and cattle, create differing objectives between user groups (Wheeler and Willoughby 1993). Forestry objectives are focused on tree regeneration, while cattle producers demand accessible forage production. A broader, integrated management approach is needed to incorporate the objectives of both the forestry and grazing industries.

Forest companies are concerned that cattle grazing on harvested areas may prevent achievement of reforestation standards, and therefore blame livestock grazing as being the cause of lack of regeneration. In contrast, grazing disposition holders are concerned about the long-term effects of timber harvesting on forage supply. The rapid regrowth of aspen stands following harvesting may create a natural barrier to cattle movement, thus restricting livestock access to forage (Willoughby 1995).

Management conflicts could be eliminated, and mutual benefits achieved, if an integrated management approach was taken. McLean (1979) explained that clear-cut harvesting opened the forest canopy and provided increased palatable forage for livestock and wildlife. Livestock grazing can indirectly improve timber production by controlling competition of less desirable herbaceous and woody species (Wood 1972, and Beveridge et al. 1973) and reducing fire hazards (Adams 1975). Such integration of industry interests is vital in promoting a common management plan that achieves mutual resource benefits.

There was a critical need to identify the effect of cattle utilization on aspen regeneration in clear-cuts created by current forest harvesting technology. This study was conducted to test the hypothesis that cattle utilization does not reduce aspen regeneration on three levels of forest harvesting skidding disturbances (light, heavy, and very heavy) at two years post-harvest.

Associated Research

Summer harvesting by full-tree skidding is an effective means of removing excessive shrub and herbaceous competition, and scarifying litter to maintain a dominant aspen stand (Zasada and Tappeiner 1969a, Bella 1986, Navratil 1991). Because complete removal of the aspen stand removes apical dominance, increases soil temperature, rooting temperature, and light penetration, prolific suckering is initiated (Maini and Horton 1966, Steneker 1974, Bella 1986, Navratil 1991). Summer harvesting during low root carbohydrate levels, may reduce the number and vigor of aspen suckers (Navratil 1991). Because harvesting caused soil disturbance and compaction, the aspen root systems were susceptible to injury (Maini and Horton 1964, Perala 1978, Zasada and Tappeiner 1969a) and as a result aspen regeneration is reduced (Weingartner 1980, Zasada and Tappeiner 1969a, Navratil 1991).

Because aspen is an important source of forage for domestic livestock, the intensity of cattle stocking influences aspen regrowth. Controlled cattle grazing and prescribed burning on noncommercial aspen forests was used as a management tool to convert decadent aspen stands to productive grasslands (Alexander 1995, Fitzgerald and

Bailey 1984). Under controlled grazing conditions, high stocking limited aspen regrowth (Bailey 1986), whereas light stocking did not affect aspen survival (Bailey and Arthur 1985).

Grazing intensity also affected understory species abundance and composition in aspen communities. Although increased cattle grazing near Rochester, AB did not affect aspen stand overstory, understory species composition was altered, and tall plants were replaced by shorter, often exotic species (Weatherill and Keith 1969). Willoughby (1995) found that increasing grazing pressure decreased shrub and forb layers in the understory, which altered aspen community types and species diversity. Such altering of understory composition resulted in a prominence of the following low forbs: strawberry (*Fragaria virginiana*), bunchberry (*Cornus canadensis*), wintergreen (*Pyrola asarifolia*), and clover (*Trifolium* spp.). By reducing the prominence of native plants, heavier grazing pressure decreased species diversity and invasive species such as Kentucky bluegrass (*Poa pratensis*), dandelion (*Taraxacum officinale*), and clover (*Trifolium* spp.) encroached (Willoughby 1995).

Little research has been conducted into the cumulative effects of livestock grazing and forestry harvesting on aspen regeneration and forage supply in the aspen forests of Alberta (Alexander and Bailey 1992). The Campbell Creek grazing trial was initiated in 1983 to monitor the effect of moderate livestock grazing pressure (1 AUM/acre) on aspen cut-blocks seeded with tame forages (Wheeler and Willoughby 1993, Sundquist 1995). Eight years after harvesting, grazed sites were stocked with 24 200 stems/ha as compared to 36 000 stems/ha at ungrazed sites. At ten years post-harvest, aspen stocking patterns were maintained with 33 000 stems/ha with grazing and 38 000 stems/ha without grazing.

Average stem height and volume were greater with grazing, indicating that grazing may be beneficial to sucker vigor by reducing vegetative competition. In comparison, Roy and Rangen (1994) surveyed three grazing intensities (no, light, and heavy) on 3-4 year old aspen-balsam poplar cut-blocks near Nojack, Alberta. The intensity of grazing had no effect on aspen density, although stem height was reduced.

To maintain adequate forage production and range condition, management schemes are required to distribute cattle grazing pressures. Poor cattle distribution, which was influenced by cattle behaviour, created uneven grazing pressure (Roath and Krueger 1982). Important parameters affecting animal behaviour included: distance to water, topography, forage, temperature, and humidity.

Road construction enhanced cattle distribution by creating a gateway through broken terrain. Harvested cut-blocks have a network of logging roads and skid-trails, which created major corridors throughout the area (Roath and Krueger 1982). Presence of slash and other logging debris reduced livestock accessibility, which altered grazing patterns and forage utilization (Nordstrom 1984). Roath and Krueger (1982) found cattle entered cut-blocks from main access roads and returned to these access points during nongrazing periods. This continual cycling, in and out of the cut-block, created an uneven grazing pressure, with heavier utilization near access roads and lighter utilization in more distant areas. Furthermore, research on cattle utilization patterns associated with plant communities across the experimental area indicated that plant communities associated with upland sites received higher utilization than lower topographic areas (Willoughby 1994).

The season of cattle grazing has greatly influenced aspen survival following forest removal. Research has found that cattle grazed aspen more readily later in the growing season (August) than earlier (June) (Smith et al. 1972, FitzGerald and Bailey 1984, and FitzGerald et al. 1986). Early in the growing season cattle avoided aspen forage until the herbaceous species had been consumed; however, aspen was selected later in the growing season even with the presence of alternative forages (FitzGerald and Bailey 1984). Zehngraff (1946) reported that suckers released by spring logging and emerging in mid-summer were not thoroughly hardened off by fall and, consequently, were winter-killed. Therefore, grazing in the fall released some aspen suckers that were killed by the cold climatic conditions. Late August defoliation may have prevented or delayed dormancy development (FitzGerald and Bailey 1984), as the synthesis and transport of abscisic acid (required for preparing the plant for dormancy) was removed during grazing. Total removal of leaves in the fall removed the source of abscisic acid and left the plant vulnerable to winterkill (FitzGerald and Bailey 1984).

EXPERIMENTAL AREA:

Location

The experimental area was located 15 miles north of Nojack, Alberta, west of Highway 751 (Section 19-21, 28-30, Township 056, Range 11, West of the fifth meridian).

Climate

Wide distribution of aspen across North America reveals indicates that it is adaptable to a range of climatic and microsite conditions. Cold continental and boreal climates are ideal conditions for aspen growth, as aspen had a high resistance to frost and freezing conditions without snow cover (Haeussler and Coates 1986). Aspen is generally adapted to well-drained uplands. In addition to its low water demands, aspen stands and emerging suckers are shade intolerant, requiring full sunlight for optimal stand growth and survival.

Geology and Soils

Parent material, deposited by continental ice sheets, was early tertiary till of Paskapoo Formation origin (Alberta Energy and Natural Resources 1978). This geological formation was characterized by horizontally bedded, medium to weakly cemented sandstone, soft shale beds, coal, and tuff. The landscape was characterized by sinuous, narrow till plains elevated between 2800 to 3200 feet Above Sea Level (ASL) and was overlain by a shallow, discontinuous outwash and slopewash deposit material. The landscape topography was moderately well drained with undulating (2-5% slope) to moderate rolling (9-15%) slope. Soils consisted of orthic gray luvisol, clay loams from the Hubalta soil series. McNabb (1994) showed an average bulk density of 1.18 Mg m^{-3}, within the 0-10 cm soil depth, within these soil types. These heavy clay soils have low organic matter and available plant nutrients, such as nitrogen and potassium, creating poor to fairly good arable soil (Twardy and Lindsay 1971).

Vegetation

The experimental area was situated in the Lower Boreal Cordilleran Ecoregion and the Southern Alberta Uplands Ecodistrict (Strong and Leggat 1992). Prior to harvesting, the area was dominated by *Populus tremuloides-Populus balsamifera/Alnus crispa/Calmagrostis canadensis* situated along midslope positions. Lower, moister landscape positions contained *Populus tremuloides- Populus balsamifera/Alnus tenuifolia-Alnus crispa/Calamagrostis canadensis*, while drier uplands produced *Populus tremuloides-Populus balsamifera/Fragaria virginiana/Calamagrostis canadensis* (Willoughby 1994). Average biomass production was 1459 kg/ha, although a high cover of alder in the understory limited livestock use (Sundquist et al. 1997).

Forest Harvesting

The forest harvesting system included clear-cutting with full-tree skidding in alternating cut-and-leave blocks on a two-pass system. Weyerhaeuser Canada Ltd. supervised the logging operation according to the Alberta Timber Harvesting Planning and Operation Ground Rules (1994) and the Weyerhaeuser Annual Operating Plan. Logging services where provided by Art Peyton Logging Ltd.

Full-tree skidding

Full-tree harvesting system limited work at the stump to falling the tree by a feller-buncher. The trees were forwarded by a four-wheel drive, rubber-tire grapple skidder from the stump to the decking site for limbing and cutting into shorter logs (2.6 m) (Zasada and Tappeiner 1969a, Weyerhaeuser 1996). Skidding created a series of long narrow forest trails (skid-trails) from stump to decking sites; repeated use of skid-trails removed standing vegetation and increased soil exposure.

METHODOLOGY:

Experimental Design

A split plot design was used with three blocks in Early Season Grazing (ESG) and three in Late Season Grazing (LSG). In each block, plots were established to measure grazing effects and subplots to measure forest harvesting effects. Three skidding treatments (light, heavy, and very heavy) were located within each grazing treatment. Six, 2 m^2 permanent plots were established within each grazing by skidding treatments.

Measurements

Aspen and populus (aspen + balsam poplar) stem density, stem height and diameter, were measured within each permanent 2 m^2 plot, for each grazing by skidding treatment combination. These stem characteristics were measured at the end of July and September to account for each grazing season treatment. Aspen stem density and populus stem density were recorded separately in stem/m^2. The average height and diameter of the five tallest aspen and populus suckers was recorded. Height measurements were recorded in centimeters, from the organic/mineral soil surface to the tip of the terminal bud. Vernier calipers were used to measure basal stem diameter (at ground level) in millimeters. Stem damage was recorded on grazed treatments as the percentage of stems browsed and/or trampled.

Two variables adapted from Bates et al. (1993) were used to identify regeneration response to harvesting and grazing: (*i*) total aspen stem length, a variable that integrated both stem density and height by multiplying average plot stem height with average plot stem density, and (*ii*) total populus stem length to account for the occurrence of aspen and balsam poplar.

Forage biomass yields were recorded on three grazing treatments: 1) ungrazed, 2) first year grazed and second year ungrazed, and 3) two years grazed following each grazing season. Ungrazed treatments were sampled within a permanent exclosure, the two year grazed treatment was sampled outside the permanent exclosure, and following the first year, a temporary 2 m^2 exclosure (cage) was used to exclude the second year of grazing. Samples were clipped to within 1 cm of the ground surface from a 0.5 m^2 quadrat. Samples were separated into graminoids, shrubs and forbs, aspen, and balsam stems, dried, weighed, and recorded in grams/m^2.

Percent utilization for each grazing treatment was calculated using temporary 2 m^2 exclosures with the following formula:

$$\text{Percent Utilization} = \frac{\text{Producitivity (ungrazed)} - \text{Productivity (grazed)}}{\text{Productivity (ungrazed)}} \times 100$$

Data Analysis

Because blocks subjected to early season grazing were in a different location from those exposed to late season grazing, no statistical inferences were drawn about the effect of grazing season. Because of heterogeneity of error among skidding disturbances, grazing effects were estimated separately by each skidding disturbance, using the following model:

$$Y_{ijk} = S_i + e_{j(i)} + G_k + (GS)_{ik} + E_{j(ik)}$$

where:

Y = Dependent variable.
S = Season of grazing (ESG or LSG).
e = Error term for testing grazing season.
G = Grazing treatment.
GS = Grazing by season interaction.
E = Error term for testing grazing by season interaction.

Forage biomass yields were recorded on three grazing treatments: 1) ungrazed, 2) first year grazed and second year ungrazed, and 3) two years grazed following each grazing season. Ungrazed treatments were sampled within a permanent exclosure, the two year grazed treatment was sampled outside the permanent exclosure, and following the first year, a temporary 2 m^2 exclosure (cage) was used to exclude the second year of grazing. Samples were clipped to within 1 cm of the ground surface from a 0.5 m^2 quadrat. Samples were separated into graminoids, shrubs and forbs, aspen, and balsam stems, dried, weighed, and recorded in grams/m^2.

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$$Y_{ijk} = S_i + e_{j(i)} + G_k + (GS)_{ik} + E_{j(ik)}$$

where:

Y = Dependent variable.
S = Season of grazing (ESG or LSG).
e = Error term for testing grazing season.
G = Grazing treatment.
GS = Grazing by season interaction.
E = Error term for testing grazing by season interaction.

Grazing treatment effects were estimated separately by season of grazing if there was a significant grazing treatment by season of grazing interaction. Otherwise, grazing treatment effects were based on averages over seasons.

To compare grazing pressure across the three skid disturbances the following split plot model was used:

$$Y_{ijkl} = S_i + e_{j(i)} + G_k + GS_{ik} + e_{j(ik)} + T_l + ST_{il} + GT_{kl} + SGT_{ikl} + E_{ijkl}$$

Where:

Y = Dependent variable.
S = Season of grazing (ESG or LSG).
e = Error term for testing season of grazing.
G = Grazing treatment.
GS = Grazing treatment by season of grazing interaction.
e = Error term for testing grazing treatment and GS.
T = Skidding disturbance treatment.
ST = Season of grazing by skidding treatment interaction.
GT = Grazing treatment by skidding treatment interaction.
SGT = Season of grazing by grazing treatment by skidding treatment interaction.
E = Final error term.

Analysis of covariance was conducted using parent stand density as a covariate for aspen regeneration within each 2 m^2 permanent plot. Various formulae were used relating surrounding 50 m^2 suckering potential to individual plots, however none of the covariates significantly improved goodness of fit ($p < 0.05$).

RESULTS:

Due to the relatively low variation of temperature and precipitation within the experimental area, differences in weather conditions were considered negligible between one and two year post-harvest (Figure 4.1). The experimental area had a continental climate characterized by warm summers and cold winters. Average temperature during the 1995 and 1996 growing seasons was 12.8°C, with July the warmest month (16.2°C) and September the coolest month (9.2°C). Average precipitation was 76 mm, with June receiving the highest precipitation (106 mm) and September the least (33 mm).

Yearly and seasonal grazing pressure

Overall stocking within the experimental area was 1.0 AUM/ha, however grazing pressure within the primary range was much higher. Livestock utilization levels across the light, heavy, and very heavy skidding treatments are shown in Table 4.1. Greater trampling damage did occur on the heavy skidding treatment with Early Season Grazing (ESG). Furthermore, cattle utilization (66%) and stems browsed (40%) during ESG were significantly greater than during LSG, when cattle utilization and stems browsed were 34% and 7% respectively. This uneven grazing pressure further confounded any comparison of grazing season effects.

Stem characteristics

Aspen stem density was not affected by two years grazing on light, heavy, or very heavy skidding (Figure 4.2). Anova tables for aspen stem characteristics are presented in Appendices 8.1. However, two years grazing reduced populus stem density on light skid treatments from 10.6 stems/m^2 to 5.8 stems/m^2 (Figure 4.3).

Within each skid treatment, aspen stem height was evaluated by seasons of grazing (Figure 4.4). Two years of early season grazing (June-July) reduced stem height on very heavy skidding from 48 cm to 17 cm. However, grazing effects, averaged across seasons, (ES and LS) reduced stem height from 99 cm to 59 cm, from 72 cm to 43 cm, and from 63 cm to 53 cm on light, heavy, and very heavy skidded treatments respectively.

The effects of two years grazing, averaged over seasons, reduced aspen stem diameter from 9.7 mm to 7.1 mm (Figure 4.5). Two years grazing further reduced stem diameter from 11.9 mm to 8.2 mm on the light skidded disturbance.

Aspen stem length was reduced from 732 cm to 317 cm by two years grazing on light skidded areas (Figure 4.6). Populus stem length was also reduced by two years grazing on light skidded areas, from 1254 cm to 376 cm (Figure 4.7).

Forage production

Anova tables for forage production are presented in Appendices 8.2. Aspen biomass was evaluated by grazing seasons within each skid treatment (Figure 4.8). Early season grazing (one year grazing + one year ungrazed and two years of grazing treatments) reduced aspen biomass on light skidded areas. Effects of two years grazing, averaged across grazing seasons (ES and LS), also reduced aspen biomass from 82 grams/m^2 to 15 grams/m^2 on light skidded areas.

Populus biomass was reduced by grazing treatments during both early and late seasons on light skidded areas (Figure 4.9). The effect of two years grazing, averaged across seasons (ES and LS), also reduced populus biomass from 92 grams/m^2 to 26 grams/m^2 on light skidded areas.

Graminoid biomass was reduced by two years of early season grazing on all three levels of skidding (light, heavy, and very heavy) (Figure 4.10). The effect of two years grazing, averaged across seasons (ES and LS), also reduced graminoid biomass from 102 to 58 grams/m^2, from 98 to 46 grams/m^2, and from 124 to 50 grams/m^2 for light, heavy, and very heavy skidded treatments respectively.

Total biomass was reduced by both one and two year early season grazing and by two years late season grazing on light skidded areas (Figure 4.11). The effect of two years grazing, averaged across seasons (ES and LS), also reduced total biomass from 400 to 172 grams/m^2, from 258 to 122 grams/m^2, and from 272 to 104 grams/m^2 for light, heavy, and very heavy skidded treatments respectively.

Aspen regeneration characteristics were summarized in Table 4.2 to illustrate the overall effects of skidding and grazing (without seasonal effects). Results showed a decline in aspen stem density, height, diameter, and forage production with increased skidding intensity, as well as the grazing effects, which further reduced stem density, height, and diameter by 30–40%. Aspen biomass was also further reduced by cattle grazing (74%) with the greatest reduction found on light and very heavy skidding disturbances (82%).

DISCUSSION AND MANAGEMENT IMPLICATIONS:

Skidding

Increased levels of skidding reduced the aspen stem density, height, diameter, and biomass production. Therefore, light skidding created the most favorable conditions for aspen regeneration. From preceding chapters it was found that heavy and very heavy skidding intensities had soil-rooting conditions less favorable for optimal aspen regeneration. However, unequal levels of aspen regeneration across the three skid treatments may have affected grazing impacts on aspen regeneration.

Distribution of Grazing Pressure

There was relatively uniform grazing pressure across the three skidding treatments (Table 4.1). Trampling damage on heavy skid areas suggested repeated cattle traffic in and out of the main cut-block area adjacent to logging roads. Such logging roads have been identified as primary travel routes through broken terrain to access abundant forage produced by skid-trails within cut-blocks (Roath and Krueger 1982). However, due to inconsistencies in cut-block design and access in the study area (i.e. seismic lines, wellsites, and pipelines), it was difficult to assess cattle behaviour, although it is generally agreed that cattle concentrate in open canopied areas. These inconsistencies also effected the level of grazing pressure between early and late grazing seasons, as cut-blocks within the early season treatment were more accessible than cut-blocks within the late season treatment. Furthermore, due to an inability to adequately control livestock movement cut-blocks within the early season treatment received longer grazing periods than late season cut-blocks. These inconsistencies restricted the ability to make inferences about seasons of grazing.

Grazing Effects on Stem Characteristics

Although grazing did not affect aspen stem density, a reduction in populus stem density was evident. This grazing effect on populus stem density was invalidated by a prominence of balsam poplar on a single permanent exclosure. Because of inconsistencies in populus stem density within a given site, it cannot be concluded that grazing affected stem density.

Aspen stem vigor and stem lengths were reduced by two years of grazing. This conclusion is supported by the work of Roy and Rangen (1994), who showed that increased grazing intensity on deciduous cut-blocks in west-central Alberta reduced stem growth (i.e. stem height) but had no effect on stem density. In contrast, a report by Sundquist (1995) at ten years post-harvest showed that grazing decreased aspen stem density and increased height and volume, with 33 000 stems/ha on grazed treatments and 38 000 stems/ha on ungrazed treatments. It was suggested that grazing accelerated the aspen stand natural thinning process, reducing competition and thus stimulated growth of the surviving trees (Sundquist 1995). Inconsistencies in grazing effects on aspen stem density and vigor were likely related to differences in grazing pressure (Jones 1983). This identified a need to assess different grazing intensities on stem density and vigor.

Although grazing induced reductions in aspen stem height were evident on all three skid treatments, light skidded areas were the most susceptible to stem reductions from grazing. The potential for stem losses by grazing may be greater on light skidded areas due to a higher stem production on this skid treatment.

Grazing Effects on Forage Production

Two year grazing effects reduced grass and total biomass production across all three levels of skidding. Aspen and populus biomass, however, were reduced only on light skidded areas. As previously mentioned, the dominance of aspen biomass in light skid areas of the cut-block increased the potential loss and increased grazing effects on aspen production in this skid treatment.

Although there was abundant forage production on all cut-blocks the carrying capacity will likely decline due to the predominance of aspen stems within late season grazed cut-blocks. In the early season grazed cut-blocks there will likely be continuous access to forage for livestock, partly due to the intense grazing pressure that undoubtedly limited aspen growth. However, on late season grazed cut-blocks, which permitted the establishment of aspen stems before cattle entered, aspen stem have advanced enough that it has created a barrier to cattle entry. Light grazing pressure combined with two consecutive years of deferring cattle has benefited aspen growth but reduced cattle grazing to cleared haul roads.

Timing of Grazing

Although inferences regarding the effect of grazing seasons on aspen regeneration are not valid, results showed that early season grazing reduced aspen biomass more than late season grazing. The effect of early season grazing was supported by Bailey and Arthur (1985), who found that spring grazing affected the number of stems browsed and the mortality rate per sucker five and seven times greater respectively, than fall grazing. Heavy spring grazing (2.3 AUM/Ac.) produced the highest mortality rate of aspen suckers at 58%, as cattle preferred the tender shoots and emerging green leaves (Bailey and Arthur 1985). Because the cut-blocks that were susceptible to early season grazing provided primary range for cattle, emerging suckers were thereby impacted by heavy grazing pressure. Early season grazing, therefore, permitted defoliation of emerging suckers at a time of the lowest root carbohydrate reserves (Friesen et al. 1965, Schier and Zasada 1973), thus decreasing aspen regeneration.

Late Season Grazing (LSG) had little effect on aspen regeneration due to relatively high root carbohydrate reserves and a relatively light grazing pressure. Although LSG did reduce populus biomass, it is believed that biomass differences were greatly confounded by highly variable site effects. FitzGerald and Bailey (1984) reported that heavy late season grazing eliminated aspen regeneration, as defoliation prevented normal dormancy development thus leaving aspen suckers vulnerable to winter kill. This project suggested that grazing pressure by LSG was relatively light; aspen stems were able to lignify and achieve dormancy to sustain stem survival. A follow-up study by Bailey et al. (1990) indicated that long-term effects of grazing season were negligible because grazing intensity ultimately determined stem survival. Although timing of grazing affected the rate of succession, six years of short duration heavy grazing controlled aspen regeneration in both early and late seasons. This verified our study results, as grazing intensity was twice as much in ESG versus LSG (Table 4.2). Repeated removal of tops followed by emergence of new suckers depleted nonstructural carbohydrates in roots (Schier 1976), ultimately restricting stand survival. However, without periodic heavy grazing, quick emerging aspen suckers over-top herbaceous and woody species, creating an aspen forest community (Bailey et al. 1990).

Regeneration Standards:

After 5 years post-harvest, a regeneration survey requires 7 500 stems/ha with an average stem height of 160 cm on deciduous cut-blocks (Anonymous 1996). Although grazing reduced aspen stem vigor, in this project, it was unknown whether grazing would affect long-term sustainability of aspen timber products (Table 4.2).

Recommended minimum density and stocking levels vary and were difficult to prescribe due to the high mortality induced by competition at a site-specific level (Bella and DeFranceshi 1972). Perala (1978) advised at least 10 000 stems/ha at two years, whereas Steneker (1974) considered 6 000 stems/ha at three years as adequately stocked for supplementing natural thinning following high sucker emergence.

Initial stem densities on grazed cut-blocks would suggest aspen stocking rates (stems/ha) were sufficient to sustain long-term productivity on light and heavy skidded areas (Table 4.2). However, because grazing effects reduced, at two years post-harvest, aspen stem heights by 39 percent and biomass production by 74 percent, there are serious concerns regarding the effect of grazing on aspen stem production.

It has been argued in a number of studies (Crouch 1981, Bartos and Mueggler 1982) that natural aspen thinning decreased initial stem densities by 40 percent. Although it is clear that cattle grazing effects do not selectively thin less vigorous aspen stems, a 30 percent decline in aspen stem density by two years of grazing is within the normal range of early stand mortality. However, mortality created from the natural thinning process reduced vegetative competition and thereby increased aspen stem biomass and vigor (Perala 1984). Since two years of grazing further reduced aspen stem vigor and biomass, there is reason of concern regarding the long-term aspen growing stock.

Pre-harvest stand conditions and the inherent ability of aspen to regenerate under given environmental variables affected the role of grazing on aspen regeneration. Alexander (1995) reported that in decadent aspen stands, which produced limited aspen suckers, concentrated livestock grazing eliminated aspen suckers on marginal sites. Healthy aspen stands, however, resprouted vigorously and were less susceptible to grazing effects. Obviously, the need for specific-site assessments and continual study of long-term grazing effects is required to ensure long-term aspen production.

Despite the impacts of grazing on aspen stem density (27% reduction) and height (39% reduction), very heavy skidding was more detrimental than grazing with a 62%

reduction in stem density and a 44% reduction in stem height when compared to light skidding. This reduction indicates that intensive skidding must be avoided, and further illustrates the need for on-site planning of the skidding operations. Furthermore, it indicates that combinations of very heavy skidding with livestock grazing severely jeopardizes aspen growth and survival. It is also important to note that measurements were only recorded on the microsite uplands (which occupied 51% of the cut-block area), whereas microsite depressions (which occupied the remaining 49% of the cut-block) did not regenerate aspen. Therefore, cumulative effects of site, skidding, and grazing must be considered to successfully regenerate aspen communities.

CONCLUSIONS:

Without livestock grazing, increased forest harvest skidding intensity reduced aspen stem density, height, diameter, and biomass. The cumulative effects of both forest harvesting disturbance and grazing further reduced aspen stem vigor and aspen biomass. Whether the cumulative effects of skidding and grazing, following the first two years post-harvest, will affect the long-term sustainability of timber and forage production is unclear, as is whether the timing of grazing affected aspen regeneration. A greater potential for livestock to reduce aspen regeneration obviously increased with increased grazing intensity. Although cattle grazing pressure was relatively uniform throughout the skid treatments, livestock grazing was most detrimental to aspen on the most productive skid disturbances. However, based on overall grazing effects, there are serious concerns with reductions in stem density and height impacting long-term wood quality and production.

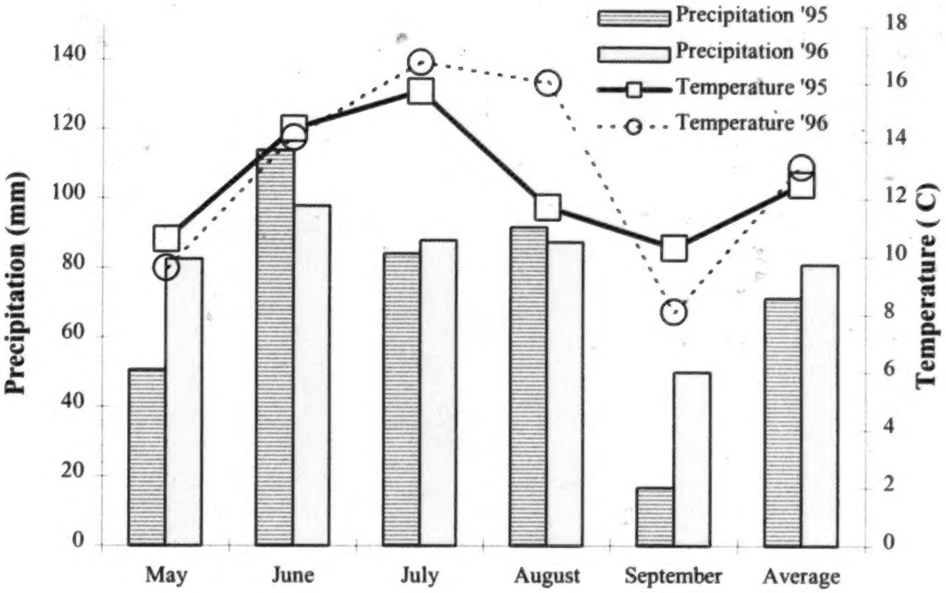

Figure 4.1 Average monthly precipitation and temperature during the 1995 and 1996 growing seasons at Cold Creek Ranger Station Nojack, Alberta.

Table 4.1 Percentage of livestock trampling and browsing on aspen stems, and total forage utilization estimates on three skidding disturbances at two years post-harvest.

Skidding	ESG			LSG		
	Tramp	Browse	Utilization	Tramp	Browse	Utilization
	(%)	(%)	(%)	(%)	(%)	(%)
Light	15a	47a	69a	19a	6a	27a
Heavy	43b	46a	63a	18a	3a	33a
VeryHeavy	21a	28a	67a	21a	13a	44a
Season	26x	40y	66y	19x	7x	34x

ESG = Early Season Grazing (June-July)
LSG = Late Season Grazing (August-September)
NS = No Season
Note: Columns (a or b) or rows (x or y) with the same letter are not significantly different according to Fisher's Least Significant Difference procedure ($p<0.05$).

Table 4.2 Characteristics of aspen regeneration under three skidding treatments, following two years of livestock grazing.

Skidding Intensity	**Aspen Density (stems/ha)**		**Aspen Stem height (cm)**		**Aspen Stem diameter (mm)**		**Aspen Biomass (kg/ha)**	
	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed
Light	34 300	26 000	99	59	12	8	1 640	300
Heavy	33 100	21 500	72	43	9	7	547	294
Very Heavy	13 200	11 400	55	35	8	6	255	47
Average	26 900	19 600	76	46	10	7	814	214
Reduction (%)	27		39		30		74	

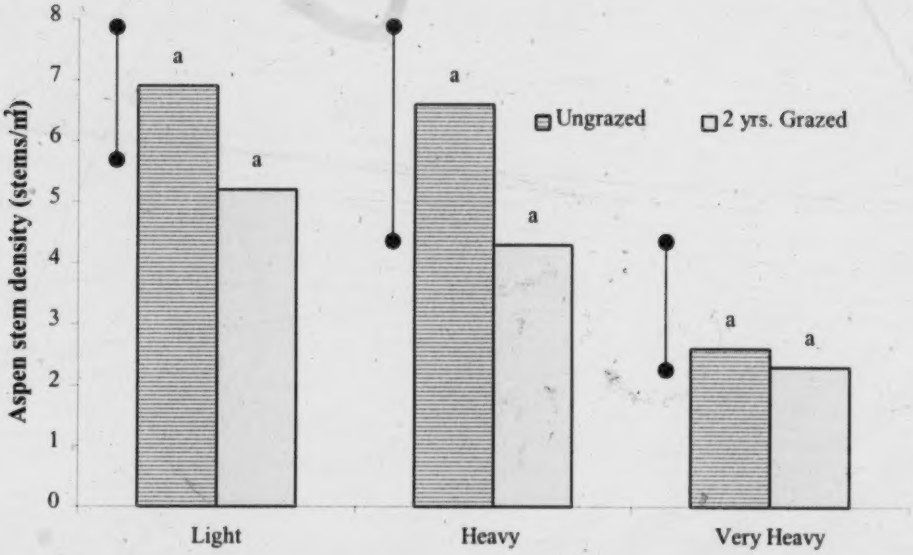

Figure 4.2 The effect of two grazing treatments on aspen stem density, within the second year, at three levels of skidding disturbance. Within each skidding treatment on aspen stem density, columns with different letters were significantly different ($p<0.05$). Vertical bars represent 95% confidence intervals of the means within each level of skidding.

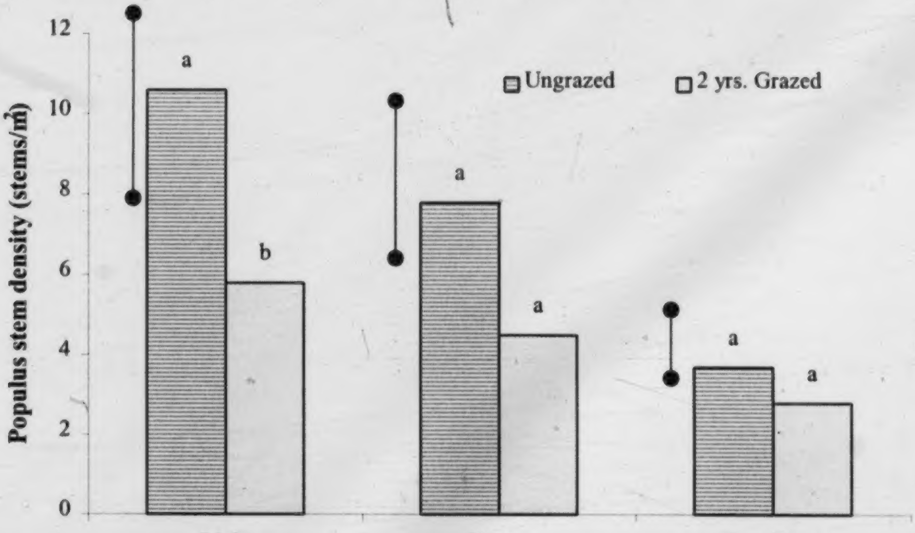

Figure 4.3 The effect of two grazing treatments on populus stem density, within the second year, at three levels of skidding disturbance. Within each skidding treatment on populus stem density, columns with different letters were significantly different ($p<0.05$). Vertical bars represent 95% confidence intervals of the means within each level of skidding.

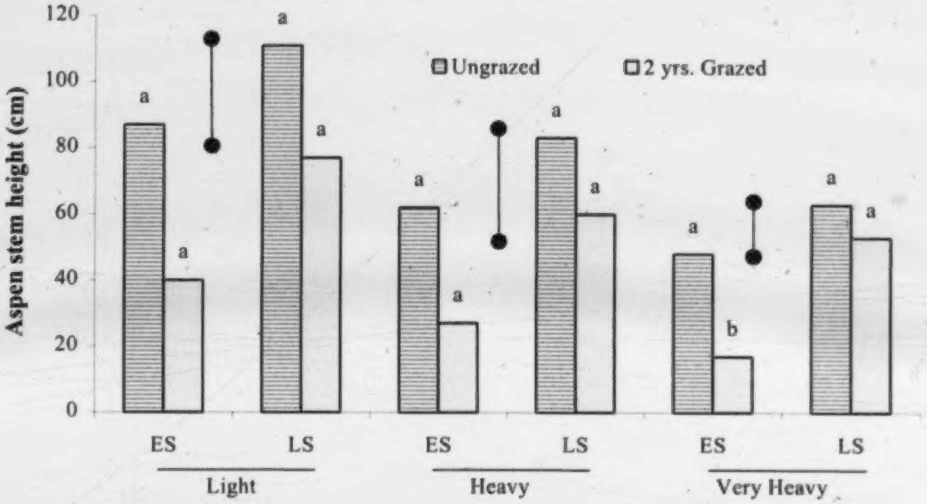

Figure 4.4 The effect of two grazing treatments on aspen stem height, within the second year, at three levels of skidding disturbance. Differences among grazing treatments, averaged over grazing seasons (ES = Early Season and LS = Late Season), were significant at all levels of skidding disturbance ($p<0.05$). The interaction between grazing treatment and season of grazing was significant. Therefore, grazing treatments were compared separately for each combination of grazing season and skidding disturbance; columns with different letters were significantly different ($p<0.05$). Vertical bars represent 95 % confidence intervals of the means within each level of skidding.

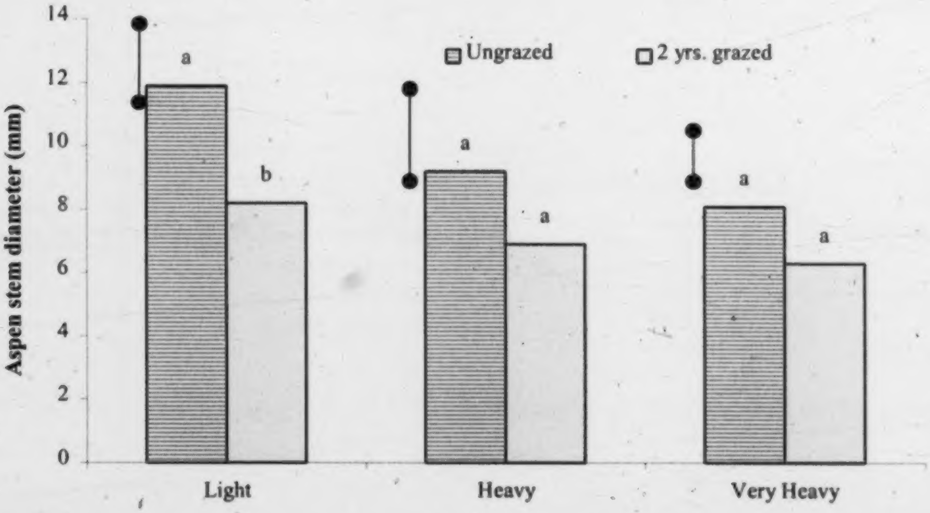

Figure 4.5 The effect of two grazing treatments on aspen stem diameter, within the second year, at three levels of skidding disturbance. Within each skidding treatment on aspen stem diameter, columns with different letters were significantly different ($p<0.05$). Vertical bars represent 95% confidence intervals of the means within each level of skidding.

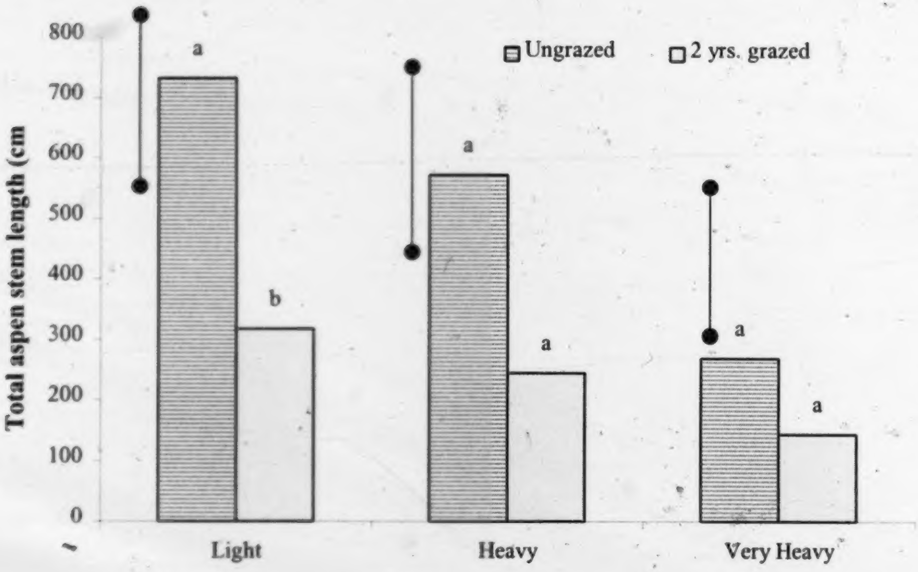

Figure 4.6 The effect of two grazing treatments on total aspen stem length, within the second year, at three levels of skidding disturbance. Within each skidding treatment on aspen stem length, columns with different letters were significantly different ($p<0.05$). Vertical bars represent 95% confidence intervals of the means within each level of skidding.

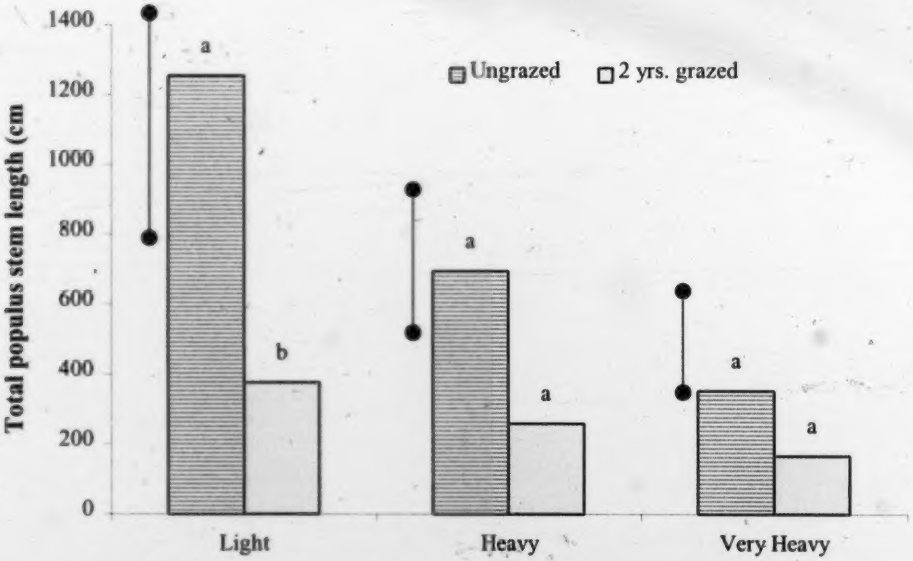

Figure 4.7 The effect of two grazing treatments on total populus stem length, within the second year, at three levels of skidding disturbance. Within each skidding treatment on populus stem length, columns with different letters were significantly different ($p<0.05$). Vertical bars represent 95% confidence intervals of means within each level of skidding.

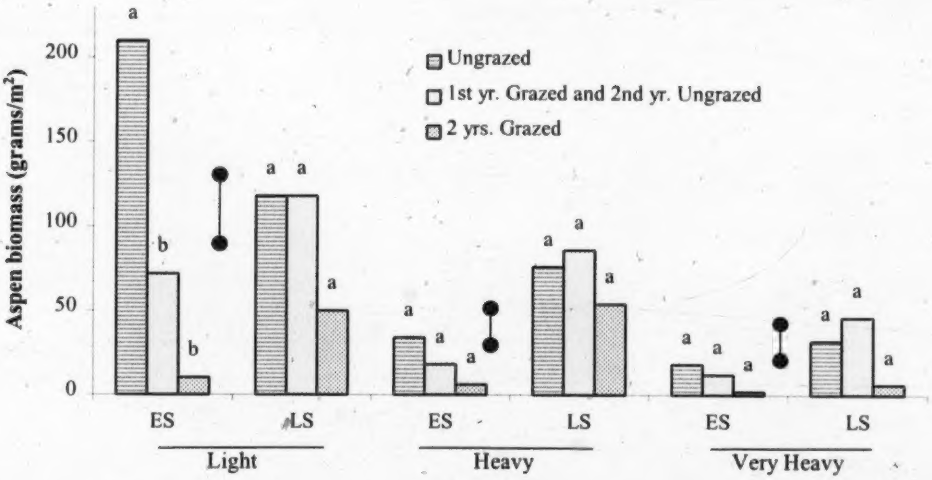

Figure 4.8 The effect of three grazing treatments on aspen biomass, within the second year, at three levels of skidding disturbance. Differences among grazing treatments, averaged over grazing seasons (ES = Early Season and LS = Late Season), were significant only for the light skidded treatment ($p<0.05$). Therefore, grazing treatments were compared separately for each combination of grazing season and skidding disturbance; columns with different letters were significantly different ($p<0.05$). Vertical bars represent 95 % confidence intervals of the means within each level of skidding.

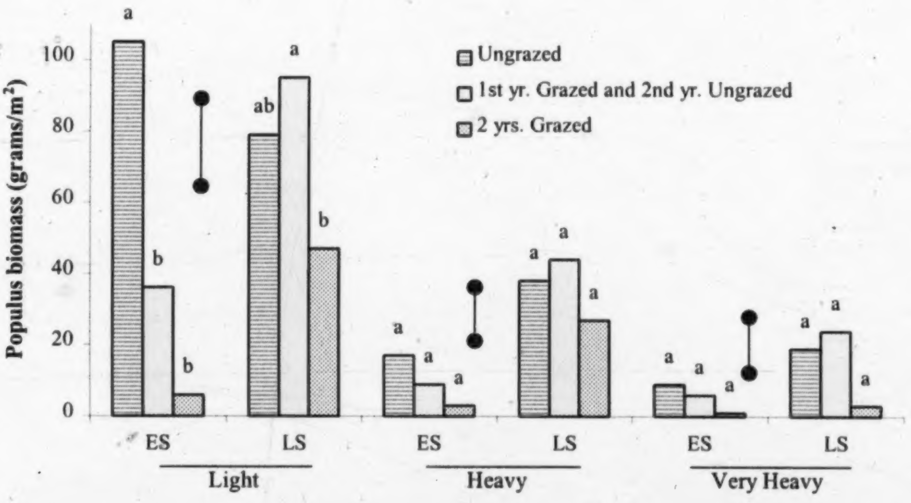

Figure 4.9 The effect of three grazing treatments on populus biomass, within the second year, at three levels of skidding disturbance. Differences among grazing treatments, averaged over grazing seasons (ES = Early Season and LS = Late Season), were significant only for the light skidded treatment ($p<0.05$). Therefore, grazing treatments were compared separately for each combination of grazing season and skidding disturbance; columns with different letters were significantly different. Vertical bars represent 95 % confidence intervals of the means within each level of skidding.

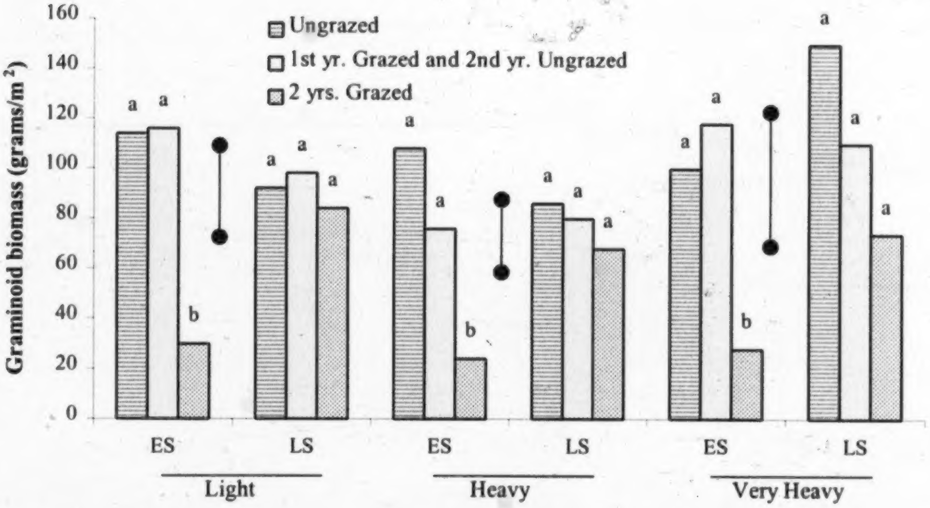

Figure 4.10 The effect of three grazing treatments on graminoid biomass, within the second year, at three levels of skidding disturbance. Differences among grazing treatments, averaged over grazing seasons (ES = Early Season and Late Season = Late Season), were significant at all levels of skidding disturbance ($p<0.05$). Therefore, grazing treatments were compared separately for each combination of grazing season and skidding disturbance; columns with different letters were significantly different. Vertical bars represent 95% confidence intervals of the means within each level of skidding.

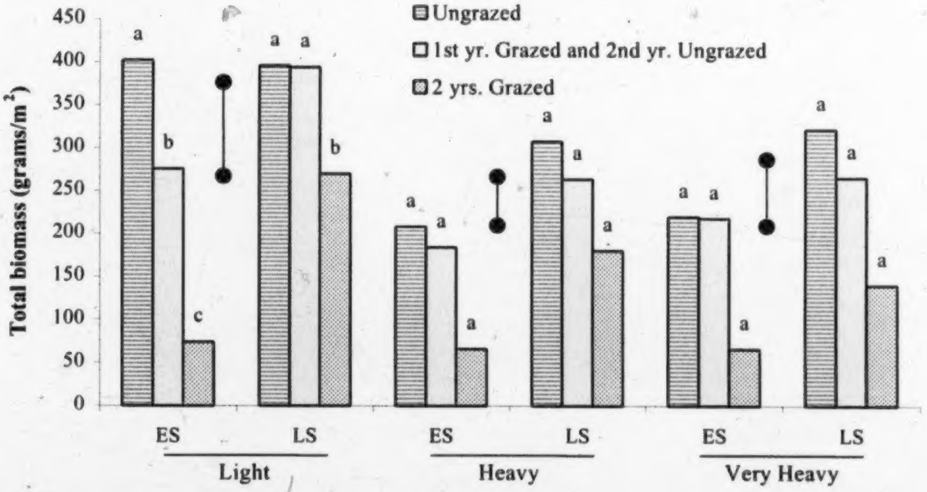

Figure 4.11 The effect of three grazing treatments on total biomass, within the second year, at three levels of skidding disturbance. Differences among grazing treatments, averaged over grazing seasons (ES = Early Season and Late Season = Late Season), were significant at all levels of skidding disturbance ($p<0.05$). Therefore, grazing treatments were compared separately for each combination of grazing season and skidding disturbance; columns with different letters were significantly different. Vertical bars represent 95% confidence intervals of the means within each level of skidding.

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V. MANAGEMENT IMPLICATIONS, AND CONCLUSIONS

MANAGEMENT IMPLICATIONS:

Integrated resource management in which livestock producers, timber industries, and public land administrators establish communication, and compromise, to facilitate long-term timber and forage benefits is critical for continued aspen regeneration. Ideal management integration would involve the development of a long-term harvesting-silviculture-range plan administered by resource users and land managers prior to harvesting. This would encompass the objectives of each user, highlighting the most feasible management options that sustain forage and fibre production.

Under certain conditions, harvesting activities can reduce aspen suckering; therefore, harvesting prescriptions and scheduling are required on a site-specific basis. To achieve sustainable aspen production, resource planning should not be based on timber volumes but on site conditions. Although it is impossible to isolate specific environmental or physiological variables influenced by harvesting, there must be an understanding of the impact of harvesting techniques upon them.

Forest Harvesting

Winter Harvesting

Climatic, soil, and aspen stand conditions indicated winter harvesting was the best option for aspen regeneration on summer grazing areas. Relatively wet summers with moist soils created unfavorable conditions for harvesting an aging aspen stand. Similar summer harvesting conditions have been correlated with poor aspen regeneration (Bates et al 1990, and Navratil 1991). These conditions combined with summer harvesting operations increased the potential reduction of aspen production regardless of whether grazing activities were present. Winter harvesting would protect the soil-rooting medium, required for natural regeneration, once the soils were frozen. Furthermore, winter harvesting would not disrupt summer grazing operations for the livestock producer.

Harvesting Operations

The integrated planning of harvesting with grazing is critical. Removal of aspen stands within a summer grazing area can tremendously change the grazing pattern of cattle and thereby affect their impact. Depending on access and the type of associated vegetation, removal of an aspen stand may create primary range for cattle. Without further plans to enhance the distribution of grazing pressure away from harvested cut-blocks, cattle may severely impact aspen regeneration. Furthermore, the intensity of skidding and size of the decking sites have a significant effect on aspen regeneration regardless of whether grazing is present. Nineteen percent of cut-blocks had reduced aspen production caused by heavy and very heavy skidding intensities, another nine percent was reduced by decking disturbances. Reducing the percentage of these disturbances would further enhance aspen regeneration. Restricting the number of skid passes within a given skid-trail and removing slash within the decking area would undoubtedly improve aspen regeneration. The harvesting operation is the key component for long-term forage and fibre production, as it effects both aspen regeneration and cattle behaviour.

Grass Seeding Haul Roads

In this project, inadequate aspen regeneration was indicated for haul roads and burn sites, because the critical source of vegetative regeneration, the parent rooting medium, was either destroyed or displayed little sucker emergence. Grass seeding on decking areas would increase forage production, and may remove grazing pressure from primary aspen producing areas within the cut-block. As well, it would provide long-term forage for cattle. Grass seeding is merely presented as a management option, and should not take the place of intensive harvesting and range management planning.

Range Management

Deferment of Cattle Grazing

Initial project results suggested that early season grazing prevented aspen regeneration, and although difficult to isolate grazing season effects, these results are supported by certain principles of plant physiology. Preventing early season grazing would allow root carbohydrate reserves to replenish and stems to lignify, thereby increasing stem survival. Restricting initial cattle access to cut-blocks would further enhance grazing distribution and prevent heavy early season grazing pressure. Control of cattle distribution, therefore, is the key to achieving sustainable aspen resources.

Preventing cattle access into harvested cut-blocks until aspen suckers lignify and maximize root carbohydrate reserves may reduce the effects of grazing on aspen regeneration. Such integration of a deferred rotational grazing schedule within a harvested cut-block system would provide sufficient deferment and improve grazing distribution. Other studies suggest that cattle be denied access to cut-blocks up to six years post-harvest, at which time aspen stem terminals are out of the reach of livestock

(Beveridge et al. 1973, Adams 1975). Prevention of livestock access to cut-block areas, although positive for aspen regeneration, would encourage dense emerging suckers the and creation of a physical barrier, thereby subsequently reducing livestock access to forage (Sundquist et al. 1997).

Managing for Cattle Distribution

The key to maintaining productive aspen regeneration is to restrict continuous heavy grazing pressure. Unless techniques are used to distribute grazing, cattle will congregate in open canopied areas. Implementing a salting program, establishing additional water dug-outs away from primary range (i.e. wellsites, pipelines, and cut-blocks), and herding can increase cattle distribution while reducing heavy grazing pressures. Cross-fencing and implementing rest-rotation grazing systems, however, remain the best alternatives to achieving the management objectives. Without such management, cattle will concentrate on cut-blocks and other accessible ranges, further jeopardizing the sustainability of timber and forage production.

Stocking Rates

Livestock stocking rates, currently based on forage production at two years post-harvest, would provide forage for 0.5 ha/AUM. To ensure sustainable aspen wood production, however, suggested stocking rates are between 1.0 and 1.5 ha/AUM based on forage production for a mature aspen community type (Sundquist et al. 1997). Stocking rates must also be adjusted to account for environmental variables (i.e. moisture regime, nutrient regime, soil drainage, elevation, and slope), canopy cover of unpalatable species (i.e. Alnus spp., *Corylus cornuta,* and *Symphoricarpos occidentale*), and the inherent ability of the aspen stand to regenerate following harvesting. Of key importance is effective management of cattle distribution, without which properly assessed stocking rates are negligible.

CONCLUSIONS:

Soil disturbance measurements verified a skidding intensity gradient with five levels of skidding (no, light, moderate, heavy, and very heavy). As well, soil compaction increased with moderate and heavy skidding. Also identified within experimental cut-blocks were three discrete decking disturbances (slash, burn, and road).

The effect of full-tree skidding indicated that aspen regeneration was optimized by a light to moderate skidding disturbance regime. Although increased skidding intensity affected stem density, vigor, and biomass, the skidding operation was an effective means of suppressing apical dominance and achieving productive aspen stands with abundant forage production for livestock and wildlife. Skidding on upland sites, which incorporated 91% of the cut-block area, was an effective means of regenerating aspen although intense skidding (7% of the harvested area) create serious concerns. Decking disturbances, although only 9% of the cut-block area, were not conducive to regeneration of aspen stems, and would therefore contribute to long-term loss of sustainable aspen production. In total 16% of the harvested area has serious problems regenerating vigorous aspen stems, however this percentage could potentially double if consideration was taken for the lack of aspen regeneration on low-lying microsite depressions (49% of the harvested area).

Grazing further reduced aspen stem vigor and biomass on three levels of skidding. Whether the cumulative effects of skidding and grazing will affect the long-term sustainability of timber and forage production remain unclear after the first two years of the study. Due to the inconsistencies in grazing pressure and site conditions, the effects of early versus late season grazing on aspen regeneration also remain unclear. However, the potential for livestock to reduce aspen regeneration increased as grazing intensity increased. Although cattle grazing pressure was relatively uniform throughout the skid treatments, grazing was most detrimental to aspen on the most productive skid disturbances. However, based on overall grazing effects, there are serious concerns with reductions in stem density and height impacting long-term wood quality and production.

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APPENDICES

6.1 Appendices for Soil and Ground Surface Disturbances on Skidded Disturbances.

Table 6.1.1 Analysis of variance for course woody debris on skidding disturbances. Block (B) included harvested cut-blocks. Skidding disturbance treatment (S) was the main plot and included no-skid, light, moderate, heavy, and very heavy skid disturbances. The probability of linear and quadratic trend analysis is also presented.

Source	DF	F-value	Prob.
Block (B)	5	1.52	0.2289
Skid (S)	4	1.41	0.2681
Error	20	--	--
Linear	20	--	0.1486
Quadratic	20	--	0.1197

Table 6.1.2 Analysis of variance for fine woody debris on skidding disturbances.

Source	DF	F-value	Prob.
Block (B)	5	2.13	0.1038
Skid (S)	4	5.54	0.0036
Error	20	--	--
Linear	20	--	0.0007
Quadratic	20	--	0.8307

Table 6.1.3 Analysis of variance for total woody debris on skidding disturbances.

Source	DF	F-value	Prob.
Block (B)	5	3.30	0.0246
Skid (S)	4	1.59	0.2158
Error	20	--	--
Linear	20	--	0.1255
Quadratic	20	--	0.1671

Table 6.1.4 Analysis of variance for litter on skidding disturbances.

Source	DF	F-value	Prob.
Block (B)	5	4.35	0.0076
Skid (S)	4	13.74	0.0001
Error	20	--	--
Linear	20	--	0.0001
Quadratic	20	--	0.8350

Table 6.1.5 Analysis of variance for debris on skidding disturbances.

Source	DF	F-value	Prob.
Block (B)	5	1.09	0.3945
Skid (S)	4	8.49	0.0004
Error	20	--	--
Linear	20	--	0.0001
Quadratic	20	--	0.2005

Table 6.1.6 Analysis of variance for exposed organic material on skidding disturbances.

Source	DF	F-value	Prob.
Block (B)	5	1.50	0.2341
Skid (S)	4	10.35	0.0001
Error	20	--	--
Linear	20	--	0.0001
Quadratic	20	--	0.3283

Table 6.1.7 Analysis of variance for exposed mineral soil on skidding disturbances.

Source	DF	F-value	Prob.
Block (B)	5	0.62	0.6890
Skid (S)	4	3.42	0.0275
Error	20	--	--
Linear	20	--	0.0055
Quadratic	20	--	0.0795

Table 6.1.8 Analysis of variance for total exposed soil on skidding disturbances.

Source	DF	F-value	Prob.
Block (B)	5	1.09	0.3955
Skid (S)	4	9.30	0.0002
Error	20	--	--
Linear	20	--	0.0001
Quadratic	20	--	0.1506

Table 6.1.9 Analysis of variance for depth of debris accumulation on skidding disturbances.

Source	DF	F-value	Prob.
Block (B)	5	6.82	0.0007
Skid (S)	4	4.19	0.0126
Error	20	--	--
Linear	20	--	0.0013
Quadratic	20	--	0.1752

Table 6.1.10 Analysis of variance for soil bulk density on skidding disturbances.

Source	DF	F-value	Prob.
Block (B)	5	13.74	0.0001
Skid (S)	4	4.59	0.0180
Error	20	--	--
Linear	20	--	0.0021
Quadratic	20	--	0.8400

6.2 Appendices for Ground Cover Estimates on Decking Disturbances.

Table 6.2.1 Analysis of variance for course woody debris on decking disturbances. Block (B) included harvested cut-blocks. Decking disturbance treatment (D) was the main plot and included no-skid compared with slash, burn, and road decking disturbances.

Source	DF	F-value	Prob.
Block (B)	5	1.95	0.1489
Deck (D)	3	12.53	0.0003
Error	15	--	--

Table 6.2.2 Analysis of variance for fine woody debris on decking disturbances.

Source	DF	F-value	Prob.
Block (B)	5	0.87	0.5278
Deck (D)	3	10.43	0.0007
Error	15	--	--

Table 6.2.3 Analysis of variance for total woody debris on decking disturbances.

Source	DF	F-value	Prob.
Block (B)	5	2.70	0.0651
Deck (D)	3	27.37	0.0001
Error	15	--	--

Table 6.2.4 Analysis of variance for litter on decking disturbances.

Source	DF	F-value	Prob.
Block (B)	5	0.79	0.5754
Deck (D)	3	84.34	0.0001
Error	15	--	--

Table 6.2.5 Analysis of variance for debris on decking disturbances.

Source	DF	F-value	Prob.
Block (B)	5	1.07	0.4195
Deck (D)	3	174.45	0.0001
Error	15	--	--

Table 6.2.6 Analysis of variance for exposed organic matter on decking disturbances.

Source	DF	F-value	Prob.
Block (B)	5	0.61	0.6913
Deck (D)	3	2.25	0.1276
Error	15	--	--

Table 6.2.7 Analysis of variance for exposed mineral soil on decking disturbances.

Source	DF	F-value	Prob.
Block (B)	5	0.97	0.4697
Deck (D)	3	37.87	0.0001
Error	15	--	--

Table 6.2.8 Analysis of variance for total exposed soil on decking disturbances.

Source	DF	F-value	Prob.
Block (B)	5	1.63	0.2176
Deck (D)	3	129.01	0.0001
Error	15	--	--

Table 6.2.9 Analysis of variance for ash on decking disturbances.

Source	DF	F-value	Prob.
Block (B)	5	0.94	0.4880
Deck (D)	3	1642.27	0.0001
Error	15	--	--

Table 6.2.10 Analysis of variance for depth of slash accumulation on decking disturbances.

Source	DF	F-value	Prob.
Block (B)	5	2.97	0.0495
Deck (D)	3	29.47	0.0001
Error	15	--	--

7.1 Appendices for aspen stem characteristics for skidding intensity.

Table 7.1.1 Analysis of variance for aspen stem density.
Year (Y) included measurements recorded at one and two years post-harvest. Skidding intensity (Sk) included no-skid, light, moderate, heavy, and very heavy skidding. Seasons (S) included measurements recorded at June and September.

Source	**DF**	**F-value**	**Prob.**
Year (Y)	1	45.65	0.0001
Y x Skid (Sk)	4	3.34	0.0254
Error 1	24	--	--
Season (S)	1	19.36	0.0002
S x Sk	4	0.43	0.7882
Error 2	24	--	--
Y x S	1	1.52	0.2288
Y x S x Sk	4	0.17	0.9519
Error 3	24	--	--

Table 7.1.2 Analysis of variance for aspen stem height.

Source	**DF**	**F-value**	**Prob.**
Year (Y)	1	8.27	0.0083
Y x Skid (Sk)	4	1.10	0.3774
Error 1	24	--	--
Season (S)	1	75.22	0.0001
S x Sk	4	0.21	0.9285
Error 2	24	--	--
Y x S	1	7.12	0.0135
Y x S x Sk	4	0.46	0.7621
Error 3	24	--	--

Table 7.1.3 Analysis of variance for total aspen stem length.

Source	**DF**	**F-value**	**Prob.**
Year (Y)	1	27.09	0.0001
Y x Skid (Sk)	4	3.55	0.0207
Error 1	24	--	--
Season (S)	1	7.34	0.0122
S x Sk	4	1.87	0.1490
Error 2	24	--	--
Y x S	1	0.11	0.7432
Y x S x Sk	4	1.53	0.2239
Error 3	24	--	--

Table 7.1.4 Analysis of variance for total populus stem length.

Source	DF	F-value	Prob.
Year (Y)	1	28.57	0.0001
Y x Skid (Sk)	4	3.83	0.0151
Error 1	24	--	--
Season (S)	1	5.09	0.0335
S x Sk	4	2.24	0.1052
Error 2	24	--	--
Y x S	1	0.01	0.9135
Y x S x Sk	4	0.31	0.8672
Error 3	24	--	--

Table 7.1.5 Analysis of variance for aspen stem diameter.

Source	DF	F-value	Prob.
Year (Y)	1	20.35	0.0001
Y x Skid (Sk)	4	1.22	0.2088
Error 1	24	--	--
Season (S)	1	--	--
S x Sk	4	--	--
Error 2	24	--	--
Y x S	1	--	--
Y x S x Sk	4	--	--
Error 3	24	--	--

7.2 Appendices for aspen stem characteristics on decking disturbances.

Table 7.2.1 Analysis of variance for aspen stem density.
Year (Y) included measurements recorded at one and two years post-harvest. Decking disturbances (D) included slash, burn, and road disturbances along with no-skid which was used as a control. Seasons (S) included measurements recorded at June and September.

Source	DF	F-value	Prob.
Year (Y)	1	0.52	0.8421
Y x Skid (Sk)	3	1.45	0.3477
Error 1	13	--	--
Season (S)	1	0.85	0.6322
S x Sk	3	1.05	0.1169
Error 2	13	--	--
Y x S	1	2.01	0.1098
Y x S x Sk	3	2.40	0.0983
Error 3	13	--	--

Table 7.2.2 Analysis of variance for aspen stem height.

Source	**DF**	**F-value**	**Prob.**
Year (Y)	1	2.99	0.1044
Y x Skid (Sk)	3	1.73	0.2039
Error 1	13	--	--
Season (S)	1	24.0	0.0002
S x Sk	3	1.99	0.1586
Error 2	13	--	--
Y x S	1	12.97	0.0026
Y x S x Sk	3	0.43	0.7312
Error 3	13	--	--

Table 7.2.3 Analysis of variance for total aspen stem length.

Source	**DF**	**F-value**	**Prob.**
Year (Y)	1	3.74	0.0752
Y x Skid (Sk)	3	2.52	0.1032
Error 1	13	--	--
Season (S)	1	2.67	0.1259
S x Sk	3	7.91	0.0030
Error 2	13	--	--
Y x S	1	0.32	0.5792
Y x S x Sk	3	0.92	0.4585
Error 3	13	--	--

Table 7.2.4 Analysis of variance for total populus stem length.

Source	**DF**	**F-value**	**Prob.**
Year (Y)	1	6.47	0.0225
Y x Skid (Sk)	3	5.02	0.0132
Error 1	13	--	--
Season (S)	1	3.63	0.0760
S x Sk	3	9.39	0.0010
Error 2	13	--	--
Y x S	1	0.58	0.4584
Y x S x Sk	3	0.15	0.9255
Error 3	13	--	--

Table 7.2.5 Analysis of variance for aspen stem diameter.

Source	DF	F-value	Prob.
Year (Y)	1	10.05	0.0031
Y x Skid (Sk)	3	6.23	0.0228
Error 1	13	--	--
Season (S)	1	--	--
S x Sk	3	--	--
Error 2	13	--	--
Y x S	1	--	--
Y x S x Sk	3	--	--
Error 3	13	--	--

7.3 Appendices for biomass production on skidding intensity.

Table 7.3.1 Analysis of variance for graminoid biomass production.
Block (B) included five cut-blocks within the experimental area. Skidding intensity was the main plot which included no-skid, light, moderate, heavy and very heavy skidding. Year (Y) included measurements recorded at one and two years post-harvest.

Source	DF	F-value	Prob.
Block (B)	4	0.56	0.6943
Skid (S)	4	1.42	0.2720
B x S	16	4.46	0.0011
Year (Y)	1	46.11	0.0001
Y x S	4	6.45	0.0017
Error	20	--	--

Table 7.3.2 Analysis of variance for shrub and forb biomass production.

Source	DF	F-value	Prob.
Block (B)	4	3.50	0.0254
Skid (S)	4	1.28	0.3112
B x S	16	0.88	0.5965
Year (Y)	1	0.33	0.5726
Y x S	4	1.35	0.2853
Error	20	--	--

Table 7.3.3 Analysis of variance for aspen biomass production.

Source	DF	F-value	Prob.
Block (B)	4	4.38	0.0105
Skid (S)	4	14.70	0.0001
B x S	16	0.88	0.6022
Year (Y)	1	18.53	0.0003
Y x S	4	3.08	0.0397
Error	20	--	--

Table 7.3.4 Analysis of variance for total biomass production.

Source	DF	F-value	Prob.
Block (B)	4	5.05	0.0056
Skid (S)	4	16.23	0.0001
B x S	16	0.91	0.5708
Year (Y)	1	4.52	0.0461
Y x S	4	2.48	0.0770
Error	20	--	--

7.4 Appendices of biomass production on decking disturbances.

Table 7.4.1 Analysis of variance for graminoid biomass production.

Block (B) included five cut-blocks within the experimental area. Decking disturbances (D) included slash, burn, and road disturbances along with no-skid which was used as a control. Year (Y) included measurements recorded at one and two years post-harvest.

Source	DF	F-value	Prob.
Block (B)	4	2.30	0.1040
Decking (D)	3	69.37	0.0001
B x D	12	2.70	0.0328
Year (Y)	1	23.40	0.0002
Y x D	3	3.94	0.0279
Error	17	--	--

Table 7.4.2 Analysis of variance for shrub and forb biomass production.

Source	DF	F-value	Prob.
Block (B)	4	3.15	0.0435
Decking (D)	3	25.56	0.0001
B x D	12	1.03	0.4679
Year (Y)	1	10.82	0.0046
Y x D	3	3.86	0.0299
Error	17	--	--

Table 7.4.3 Analysis of variance for aspen biomass production.

Source	DF	F-value	Prob.
Block (B)	4	1.40	0.2799
Decking (D)	3	24.88	0.0001
B x D	12	0.87	0.5904
Year (Y)	1	2.80	0.1138
Y x D	3	2.19	0.1288
Error	17	--	--

Table 7.4.4 Analysis of variance for total biomass production.

Source	DF	F-value	Prob.
Block (B)	4	3.25	0.0393
Decking (D)	3	104.46	0.0001
B x D	12	0.66	0.7679
Year (Y)	1	0.21	0.6528
Y x D	3	6.27	0.0051
Error	17	--	--

8.1 Appendices for the effects of two years grazing on aspen stem characteristics.

Table 8.1.1 Analysis of variance for aspen stem density on light skidded disturbances. Season (S) included early season grazing (June – July), and late season grazing (August – September). Graze treatments included two years ungrazed and two years grazed.

Source	DF	F-value	Prob.
Season (S)	1	0.94	0.3874
Error 1	4	--	--
Graze (G)	1	1.16	0.3423
S x G	1	0.74	0.4377
Error 2	4	--	--

Table 8.1.2 Analysis of variance for aspen stem density on heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	2.41	0.1957
Error 1	4	--	--
Graze (G)	1	1.79	0.2517
S x G	1	0.02	0.8916
Error 2	4	--	--

Table 8.1.3 Analysis of variance for aspen stem density on very heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	2.52	0.1874
Error 1	4	--	--
Graze (G)	1	0.23	0.6575
S x G	1	0.49	0.5231
Error 2	4	--	--

Table 8.1.4 Analysis of variance for populus stem density on light skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	0.82	0.4158
Error 1	4	--	--
Graze (G)	1	12.05	0.0255
S x G	1	1.43	0.2971
Error 2	4	--	--

Table 8.1.5 Analysis of variance for populus stem density on heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	3.70	0.1267
Error 1	4	--	--
Graze (G)	1	3.84	0.1217
S x G	1	0.56	0.4944
Error 2	4	--	--

Table 8.1.6 Analysis of variance for populus stem density on very heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	7.66	0.0504
Error 1	4	--	--
Graze (G)	1	0.96	0.3816
S x G	1	0.01	0.9331
Error 2	4	--	--

Table 8.1.7 Analysis of variance for aspen stem height on light skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	6.55	0.0627
Error 1	4	--	--
Graze (G)	1	16.81	0.0149
S x G	1	0.46	0.5360
Error 2	4	--	--

Table 8.1.8 Analysis of variance for aspen stem height on heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	5.46	0.0797
Error 1	4	--	--
Graze (G)	1	6.22	0.0673
S x G	1	0.27	0.6287
Error 2	4	--	--

Table 8.1.9 Analysis of variance for aspen stem height on very heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	12.51	0.0241
Error 1	4	--	--
Graze (G)	1	20.19	0.0109
S x G	1	5.50	0.0789
Error 2	4	--	--

Table 8.1.10 Analysis of variance for total aspen stem length on light skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	0.20	0.6777
Error 1	4	--	--
Graze (G)	1	8.88	0.0408
S x G	1	2.29	0.2052
Error 2	4	--	--

Table 8.1.11 Analysis of variance for total aspen stem length on heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	2.62	0.1811
Error 1	4	--	--
Graze (G)	1	4.40	0.1041
S x G	1	0.00	0.9544
Error 2	4	--	--

Table 8.1.12 Analysis of variance for total aspen stem length on very heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	0.40	0.5612
Error 1	4	--	--
Graze (G)	1	1.85	0.2449
S x G	1	1.15	0.3447
Error 2	4	--	--

Table 8.1.13 Analysis of variance for total populus stem length on light skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	1.65	0.2684
Error 1	4	--	--
Graze (G)	1	11.85	0.0262
S x G	1	0.79	0.4238
Error 2	4	--	--

Table 8.1.14 Analysis of variance for total populus stem length on heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	3.57	0.1317
Error 1	4	--	--
Graze (G)	1	4.51	0.1010
S x G	1	0.33	0.5914
Error 2	4	--	--

Table 8.1.15 Analysis of variance for total populus stem length on very heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	1.76	0.2551
Error 1	4	--	--
Graze (G)	1	3.13	0.1515
S x G	1	0.22	0.6621
Error 2	4	--	--

Table 8.1.16 Analysis of variance for aspen stem diameter on light skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	4.88	0.0916
Error 1	4	--	--
Graze (G)	1	19.61	0.0114
S x G	1	0.00	0.9754
Error 2	4	--	--

Table 8.1.17 Analysis of variance for aspen stem diameter on heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	5.12	0.0865
Error 1	4	--	--
Graze (G)	1	2.97	0.1601
S x G	1	0.00	0.9745
Error 2	4	--	--

Table 8.1.18 Analysis of variance for aspen stem diameter on very heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	14.15	0.0197
Error 1	4	--	--
Graze (G)	1	5.24	0.0840
S x G	1	2.64	0.1798
Error 2	4	--	--

8.2 Appendices for the effects of two years grazing on biomass production.

Table 8.2.1 Analysis of variance for graminoid biomass production on light skidded disturbances. Season (S) included early season grazing (June – July), and late season grazing (August – September). Graze treatments included two years ungrazed, first year grazed and the second year ungrazed, and two years grazed.

Source	DF	F-value	Prob.
Season (S)	1	0.17	0.7051
Error 1	4	--	--
Graze (G)	2	5.85	0.0272
S x G	2	3.54	0.0793
Error 2	8	--	--

Table 8.2.2 Analysis of variance for graminoid biomass production on heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	0.83	0.4132
Error 1	4	--	--
Graze (G)	2	9.37	0.0080
S x G	2	3.71	0.0726
Error 2	8	--	--

Table 8.2.3 Analysis of variance for graminoid biomass production on very heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	2.27	0.2064
Error 1	4	--	--
Graze (G)	2	5.84	0.0273
S x G	2	0.99	0.4143
Error 2	8	--	--

Table 8.2.4 Analysis of variance for aspen biomass production on light skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	0.01	0.9524
Error 1	4	--	--
Graze (G)	2	13.19	0.0029
S x G	2	4.51	0.0489
Error 2	8	--	--

Table 8.2.5 Analysis of variance for aspen biomass production on heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	14.28	0.0195
Error 1	4	--	--
Graze (G)	2	2.33	0.1593
S x G	2	0.58	0.5802
Error 2	8	--	--

Table 8.2.6 Analysis of variance for aspen biomass production on very heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	1.34	0.3117
Error 1	4	--	--
Graze (G)	2	2.67	0.1296
S x G	2	0.86	0.4604
Error 2	8	--	--

Table 8.2.7 Analysis of variance for populus biomass production on light skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	2.29	0.2047
Error 1	4	--	--
Graze (G)	2	13.19	0.0029
S x G	2	5.99	0.0257
Error 2	8	--	--

Table 8.2.8 Analysis of variance for populus biomass production on heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	14.43	0.0191
Error 1	4	--	--
Graze (G)	2	2.30	0.1620
S x G	2	0.70	0.5233
Error 2	8	--	--

Table 8.2.9 Analysis of variance for populus biomass production on very heavy skidded disturbances.

Source	DF	F-value	Prob.
Season (S)	1	1.81	0.2502
Error 1	4	--	--
Graze (G)	2	2.71	0.1266
S x G	2	0.82	0.4728
Error 2	8	--	--

Table 8.2.10 Analysis of variance for total biomass production on light skidded disturbances.

Source	**DF**	**F-value**	**Prob.**
Season (S)	1	5.04	0.0881
Error 1	4	--	--
Graze (G)	2	20.88	0.0007
S x G	2	3.88	0.0664
Error 2	8	--	--

Table 8.2.11 Analysis of variance for total biomass production on heavy skidded disturbances.

Source	**DF**	**F-value**	**Prob.**
Season (S)	1	15.56	0.0169
Error 1	4	--	--
Graze (G)	2	29.64	0.0002
S x G	2	0.41	0.6743
Error 2	8	--	--

Table 8.2.12 Analysis of variance for total biomass production on very heavy skidded disturbances.

Source	**DF**	**F-value**	**Prob.**
Season (S)	1	10.32	0.0325
Error 1	4	--	--
Graze (G)	2	20.30	0.0007
S x G	2	0.45	0.6504
Error 2	8	--	--